UNITED STATES ATOMIC ENERGY COMMISSION

Annual Report to Congress

OF THE

ATOMIC ENERGY COMMISSION

FOR

1966

January 1967

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LETTER OF SUBMITTAL

WASHINGTON, D.C.,
January 31, 1967.

SIRS: We have the honor to submit herewith the Annual Report of the United States Atomic Energy Commission for 1966 as required by the Atomic Energy Act of 1954.

Respectfully,

UNITED STATES ATOMIC ENERGY COMMISSION,
WILFRID E. JOHNSON.
SAMUEL M. NABRIT.
JAMES T. RAMEY.
GERALD F. TAPE.
GLENN T. SEABORG, *Chairman.*

The Honorable
The President of the Senate.
The Honorable
The Speaker of the House of Representatives.

RAW MATERIALS

During 1966, the near-term future of the domestic uranium industry brightened with the announcements of expanded plans for nuclear powerplants; present U.S. uranium reserves are adequate for near-term needs, but new ore body discoveries are needed for the future.

URANIUM PROCUREMENT

Foreign uranium procurement by the AEC terminated at the end of 1966 with the expiration of the Canadian and South African contracts.

The AEC's uranium purchases in 1966 were 1,566 tons less than in 1965. The following table shows the sources and amounts received in the past two years:

	Tons of U_3O_8 1965	Tons of U_3O_8 1966
U.S.A.	10,442	9,476
Canada	717	720*
South Africa	1,932	1,329
Total	13,091	11,525

*Includes 50.9 tons produced in 1966 under contract, but not delivered at year's end.

Domestic Uranium Production

AEC Procurement of Concentrate

Commencing January 1, 1967, uranium concentrate (U_3O_8) purchased by the AEC will be material the delivery of which was deferred by milling companies and by some independent mining companies from the 1963–1966 period, plus that derived from ores produced from eligible small mining properties, in accordance with the domestic stretch-out program announced in November 1962.[2]

On November 10, 1966, the AEC announced that it would contract with milling companies serving isolated areas for the purchase in 1967–68 of concentrate derived from ores from eligible small mining properties not served by stretch-out mills. The owners of several mills in isolated areas have requested arrangements with AEC to treat ores from eligible small properties. These and one or two other companies

[2] See pp. 69–70, "Annual Report to Congress for 1965;" and pp. 210–211, "Annual Report to Congress for 1962."

aluminum or magnesium—which neither moderate nor absorb neutrons to any large extent—while retaining the present lattice configuration of the reactor. Another concept to achieve a more efficient configuration of a resonance reactor would involve the creation of a compact and relatively homogeneous mixture of fuel, D_2O moderator, and controls. The compact core design would require extensive modifications of the present control system, moderator circulation, safety systems, etc., and could be constructed either in an existing reactor tank or in a closely adjacent new tank at about the same cost. The compact core design would have a significant productivity advantage, but would cost considerably more. Both the technical feasibility and the economic evaluation of the two concepts are under study.

RADIOISOTOPE PRODUCTION AND SALES

Radioisotopes being used, or under study for potential uses, as thermoelectric power sources are either man-made by irradiation of selected target materials with neutrons, or are recovered as byproducts (fission products) from chemical processing of "spent" reactor fuels. The increasing interest in certain radioisotopes for isotopic heat applications has stimulated technological development of cheaper and better methods for irradiating target materials in the AEC's production reactors. At the same time, chemical processes are being developed for economical recovery of highly purified isotopic products on a larger scale than previously. The current and potential uses of radioisotopes in space, terrestrial, and marine systems, and the development of the fuel sources for these uses, are discussed in Chapter 9—Isotopic Heat and Power Applications.

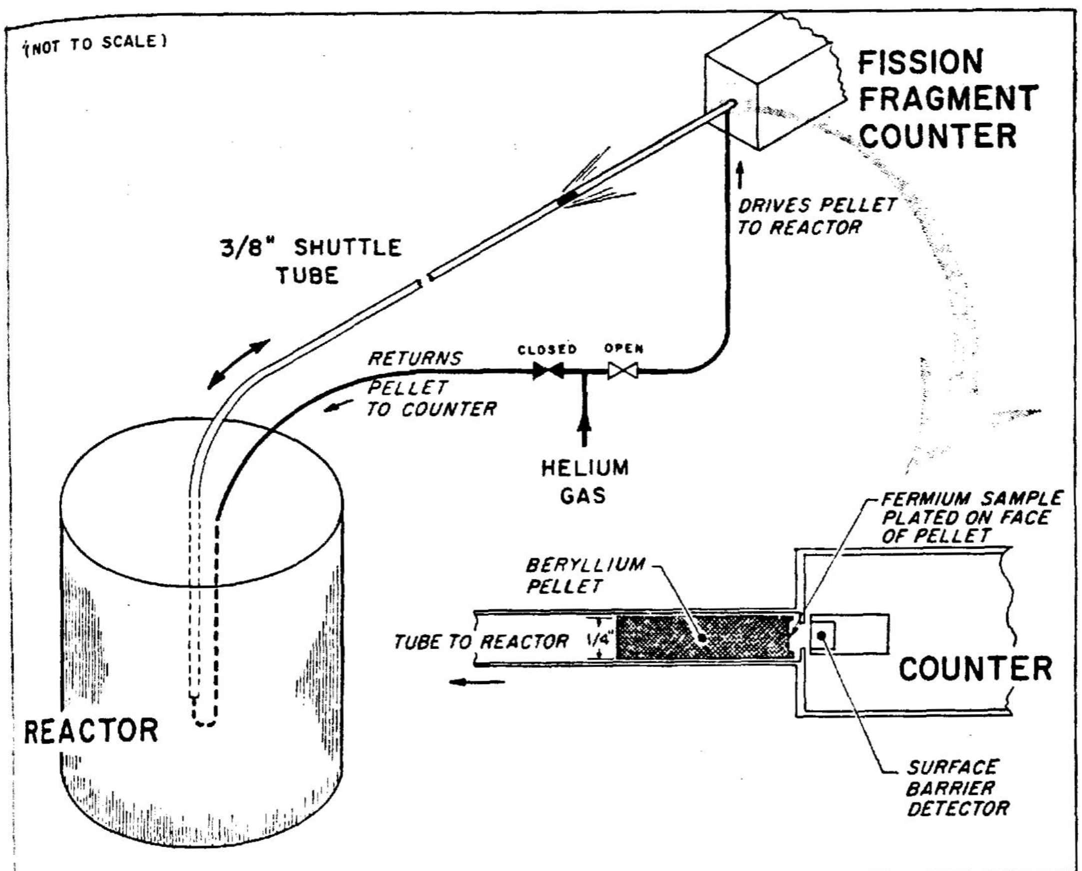
NEUTRON ADDITION PRODUCTS

Originally, the AEC's production reactors at Hanford and Savannah River were built specifically to provide fissionable material for the Nation's defense. However, because of their large size and wide range of neutron flux these reactors offer significant advantages for the production of special radioisotopes. This can be done by neutron irradiation of specific target materials, generally over a period of several months, and in some cases, years. The desired isotope ordinarily must be chemically separated from the target material after the irradiation period. The more important of the heat-producing isotopes being made directly by neutron addition reactions at Savannah River are

curium 244, plutonium 238, cobalt 60, and polonium 210. Also being produced are unique heavy element radioisotopes, such as americium, berkelium, and californium which are of scientific interest.

HIGH-FLUX OPERATION

A successful one-year demonstration of very high flux operation, for scientific as well as technical purposes, was completed at the Savannah River Plant (SRP) in February 1966. During this program, stable reactor operation was demonstrated at neutron flux levels up to 6.1×10^{15} (six quadrillion) neutrons per square centimeter per second (n/cm^2-sec.)—the highest sustained flux ever attained in any



Sample Irradiation. Diagrams show a pneumatic device for rapidly moving a sample from the center of a reactor core to a counting facility that has been developed by E. I. du Pont de Nemours & Co. engineers at the AEC's Savannah River Plant to take advantage of the high thermal neutron flux (5×10^{15} n/cm^2-sec) available in the production reactors. The sample, coated on the end surface of a pellet (see *lower right*), is irradiated in the reactor and then transported in about one second through a 75-foot-long shuttle tube for counting at a detector. The high-speed pneumatic facility was used by scientists from the Lawrence Radiation Laboratory to irradiate fermium 257 to produce fermium 258. The results have not yet been reported. Consideration is being given to using this device for additional tests during future high flux operation at Savannah River.

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reactor in the world—and at heat fluxes up to 2.66×10^6 (2.66 million) BTU per hour per square foot, and specific powers of 226 kilowatts per gram of uranium 235.

Scientific Experiments

During the SRP high-flux demonstration, research samples containing over 150 nuclides of 66 elements were irradiated for several universities and various AEC national laboratories. Irradiation of cobalt 59 produced the world's most concentrated cobalt 60 source—containing 700 curies/gram and generating 96 watts/cc of heat—for fundamental studies at the Savannah River Laboratory. Also, during this program in 1966, more sophisticated tests than those accomplished in 1965 were completed at the reactor site by scientists and engineers from the Lawrence Radiation and Savannah River Laboratories to measure the half-life of fermium 258 (see below); new isotopes from double neutron capture in stable targets were produced and tentatively identified at the reactor site by scientists from Argonne National Laboratory; an experiment confirming the hard texture of the moon observed in the Surveyor I landing was completed by scientists of the Brookhaven National Laboratory; and many other scientific experiments, the results of which are still being developed by experimentors from various universities and AEC laboratories, were completed.

Fermium Half-Life Finding

A series of irradiation tests, begun by Lawrence Radiation Laboratory scientists in 1965 in an attempt to measure the half-life of fermium 258 (Fm^{258}) was continued in 1966. While no evidence was obtained for the formation of this nuclide, the high neutron fluxes attained made it possible to set an upper limit of about 10 seconds for its spontaneous fission half-life.

The stability of Fm^{258} and Fm^{260} (158 and 160 neutron subshells, respectively) toward spontaneous fission is of key significance in determining the upper limit of nuclear stability as atomic number increases. Because of the perturbation introduced by the 152 neutron subshell, theoretical extrapolations of spontaneous fission half-lives for nuclei with neutron numbers above 156 are contradictory and allow the possibility of a recovery of stability at this level. Experiments, however, had shown a trend toward shorter spontaneous fission half-lives above the 152 neutron number.

The extremely short spontaneous fission half-life limit for Fm^{258} determined in the Savannah River experiments suggests that the recovery of stability after the 152 neutron subshell is unlikely, although

similar measurements of Fm^{260} will be necessary before reaching a final conclusion. As a consequence, theories on much of the recent spontaneous fission systematics are in danger, and equally so are the possibilities of creating heavier nuclides. Neutron capture by a rapid process such as occurs in thermonuclear explosives may lead to new odd-mass nuclei, but formation by prolonged neutron irradiation in reactors will be severely limited because of losses of key nuclides through spontaneous fission decay.

Special Reactor Products

The demand for the man-made transplutonium isotopes, especially curium 244 and plutonium 238, continues to grow as new uses for them in the space programs (see Chapter 9—Isotopic Heat and Power Applications) are found and with the opening of the National Transplutonium Program Center at Oak Ridge (see Chapter 13—Research Facilities and Projects). Efforts are continuing at Savannah River to increase the production rate for transuranium radioisotopes as well as such other special reactor products as cobalt 60 and polonium 210. Shortly after the completion of the high-flux-operation demonstration, the plutonium target elements which are being used to produce curium 244 were charged to the reactor. In addition to producing curium 244, other isotopes—polonium 210 and cobalt 60—are being produced, and numerous special irradiations are being carried out at a flux of approximately 10^{15} n/cm^2-sec.

Curium 244

Production of curium 244 (Cm^{244}) is a multistep, multiyear process. During 1966, the last irradiation step in a pilot production program which began in 1963, was underway with the irradiation scheduled for completion early in 1967. During the year, it was also found possible to increase the planned output by 50 percent at a low incremental cost by minor modifications to the irradiation schedule.

Curium 244 is being produced in a production reactor by irradiating plutonium 239 (Pu^{239}). The portion of the starting plutonium not lost through fission is converted to heavier isotopes by successive neutron capture. The plutonium thus produced, rich in the plutonium 242 isotope, is separated and irradiated further to produce americium and curium. In the current production program, the irradiation of plutonium 239 was started in 1964, and the irradiation of the plutonium 242-rich fraction was started in 1965.

Residuals reused. In the scheduled high-flux irradiations, 4.5 kilograms—instead of the previously planned 3 kg.—of curium 244 will

be produced by April 1967. Starting in September 1967, this curium 244 will be separated and purified in temporary facilities being provided at the Savannah River Laboratory. Residual plutonium 242 and americium 243 (Am^{243}) will be separated; these materials can then be used to produce additional quantities of curium 244 which has a 17.6-year half-life. The purified product will be used to characterize curium 244 as an isotopic heat source and will be available for other research needs. The work to develop curium compounds suitable for isotopic power applications supplements and is coordinated with the curium heat source work at the Oak Ridge National Laboratory. The irradiation will also produce about 20 milligrams of californium 252 (CF^{252}) as a byproduct. Californium 252 is currently being evaluated for possible use for neutron radiotherapy of cancer. Californium and berkelium (Bk), another isotope formed in the irradiation, are valuable raw materials for the production of heavier elements.

Facilities being designed. New facilities are being designed at the Savannah River Laboratory to handle quantities as large as 100 to 1,000 grams of curium 244 to permit the necessary support work on manufacturing processes for fuel form and encapsulation. The facilities are expected to be located in a new wing designated as the Isotopes Process Development Laboratory (IPDL) to the major Research and Development Building at Savannah River. The curium 244 facilities envisioned for the IPDL will permit the development of all processes up to, and including, the encapsulation of curium 244 for use in power sources.

Plutonium 238

During 1966, studies were completed of various alternatives available to the AEC to increase the long-term production of the plutonium 238 isotope. However, because the production process is lengthy and complex, little can be done to increase near-term production significantly.

Useful heat source. Plutonium 238, with an 87-year half-life, is a very attractive radioisotope for heat source purposes, especially where long service and minimum shielding requirements are needed. Plutonium 238 is made in production reactors by irradiating neptunium 237 (Np^{237}) with neutrons. Neptunium 237, however, is currently obtained only as a byproduct from thermal reactors; therefore, its present availability is dependent on large-scale manufacture of other isotopes. Alternative methods were developed to enhance neptunium 237 production. With these alternatives, significantly more plutonium 238 can be produced over extended periods, although little can be done to increase plutonium 238 availability in the near term.

Although forecasted demand for plutonium 238 may exceed its availability for irradiation of neptunium 237 from the production reactors, large amounts of plutonium 238 may be derived from by-product neptunium 237 recovered from spent power reactor fuels after the mid-1970's. This target material could be advantageously converted to plutonium 238 in the production reactors because of their relatively high neutron flux, short irradiation cycles, and available irradiation space. Thus, the production reactors may complement power reactors to provide a more abundant and inexpensive supply of plutonium 238.

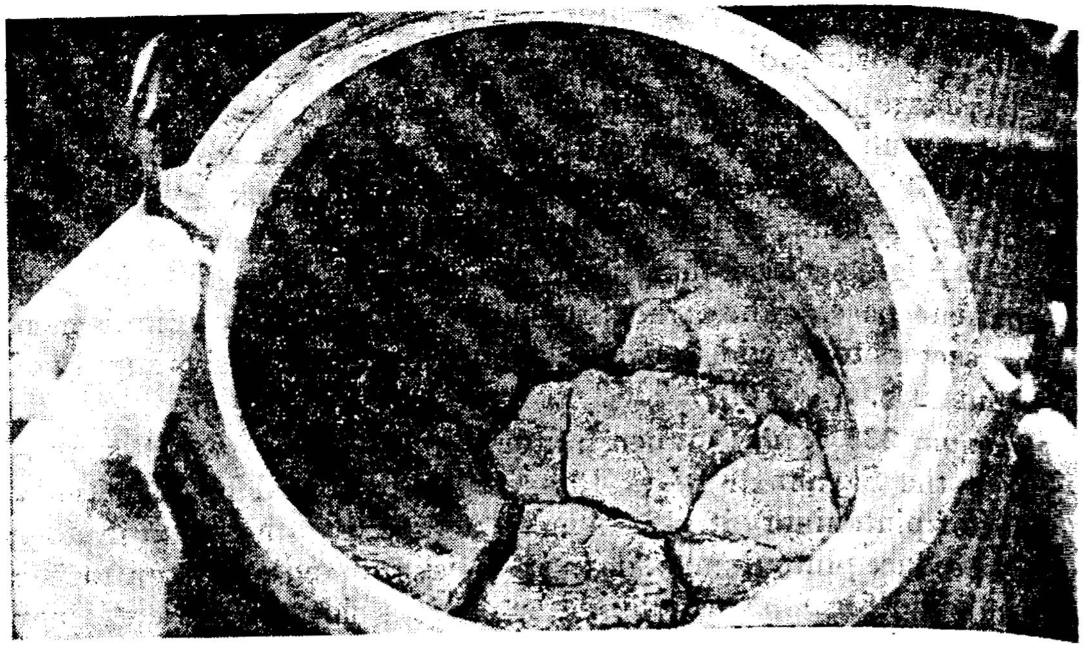
Plutonium 238 oxide. When plutonium 238 (Pu^{238}) was first produced at the Savannah River Plant, it was shipped off-plant as a solution of plutonium nitrate. A new facility was started up in July 1965 to produce plutonium oxide in an easier-to-handle powder, rather than in liquid form. Now, plutonium oxide is shipped in a container (see illustrations) that can withstand an internal pressure of 825 psig, a temperature of 925°C., and an impact equivalent to a drop of 35 feet.

Cobalt 60

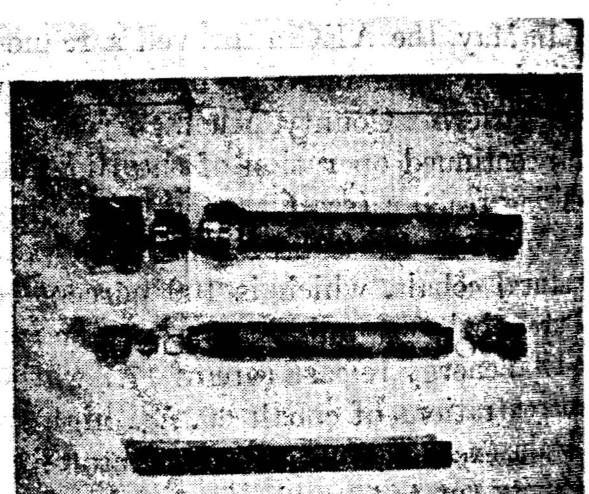
Of all the radioisotopes currently being produced, the market for cobalt 60 (Co^{60}) is the greatest. Already widely used—because of its strong gamma radiation—in industry, medicine, and research, the use of cobalt 60 for irradiation processing of foods and the possible use as a heat source now indicates a need for even more production in the future. Until 1966, the Savannah River Plant and the General Electric Co. (Pleasanton, Calif.) have been the Nation's major domestic sources of high specific activity Co^{60}.

In May, the AEC approved a request of Consumers Power Co. of Michigan to produce Co^{60} in the Big Rock Point Nuclear Power Plant in Charlevoix County, Mich. Production of Co^{60} will be incidental to the continued operation of the Big Rock Point plant as a power-producing reactor (see Chapter 17—Industrial Participation).

Cobalt 60 has a half-life of 5.3 years and is made by irradiating natural cobalt, which is 100 percent cobalt 59, in a nuclear reactor. Pure cobalt 60 would have a specific activity of 1,140 curies/gram and a total energy release rate of 17.7 watts (thermal) per gram, but high concentrations of cobalt 60, *i.e.*, high specific activities, are difficult to obtain except at very high reactor fluxes. Cobalt 60 at low specific activity (up to 50 curies/gram) has been made in large quantity in the past for applications where the gamma rays were used for radiography and product irradiation. However, there are advantages to using cobalt 60 at a high specific activity (100 to 400 curies/gram) in heat producing applications. During 1966, significant quantities of



Plutonium 238. Plutonium 238 is a man-made radioactive material produced at the AEC's Savannah River Plant (SRP) near Aiken, S.C. Among other things, it is useful as a heat and power source for space vehicles. The material is shown *above* in cake form at the SRP chemical processing area. The material is shipped to a fabrication facility off-site, where it is prepared for the ultimate user. Photos *below* show the SRP-developed container for the plutonium oxide which is actually three containers in one. Oxide is loaded into the inner container (*bottom right*) a stainless steel tube, which is then sealed on both ends with metal plugs, caps, and gas-filled O-rings. The inner container is then loaded into a stainless steel can, which is then sealed with a stainless steel cap and a "Silastic" gasket. The can is then decontaminated and loaded into an outer stainless steel container (*bottom left*) which is covered with a layer of polythene through which radial metal fins protrude. The stainless steel and the polythene absorb neutron radiation and the metal fins dissipate heat. The 15-pound container, is about 16½ inches high.



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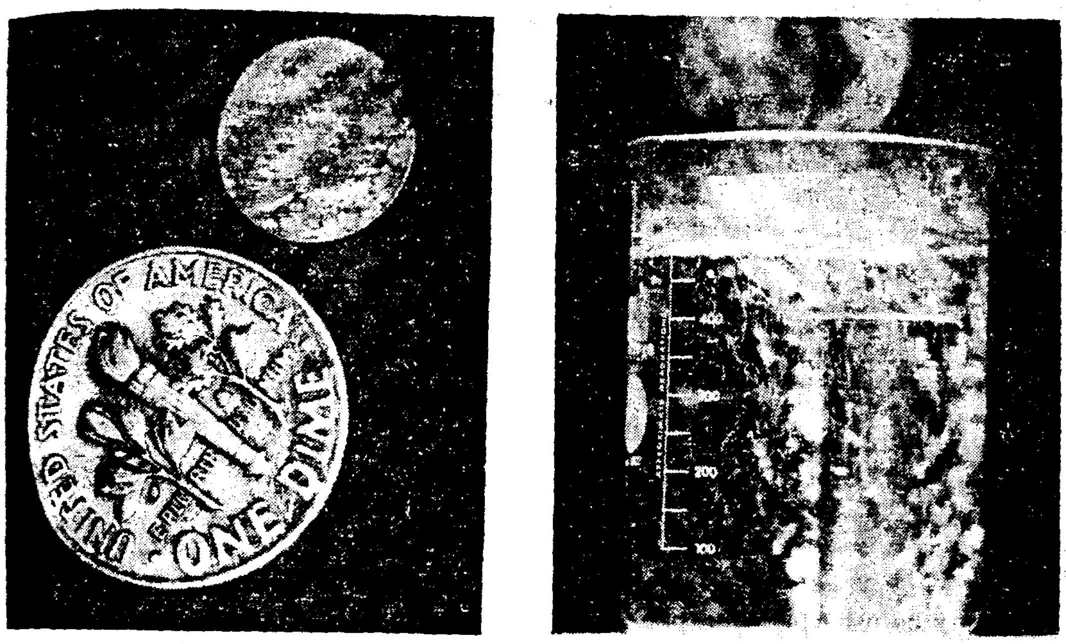
cobalt 60 at high specific activity were made in the Savannah River reactors, to be used for investigating the metallurgical properties and to provide physical data for engineering designs. In addition, a small sample (about 1⅓ grams) of cobalt was irradiated to a record specific activity of 700 curies per gram for similar experimental purposes. Such concentrated sources of penetrating energy could have uses in the radiography industry.

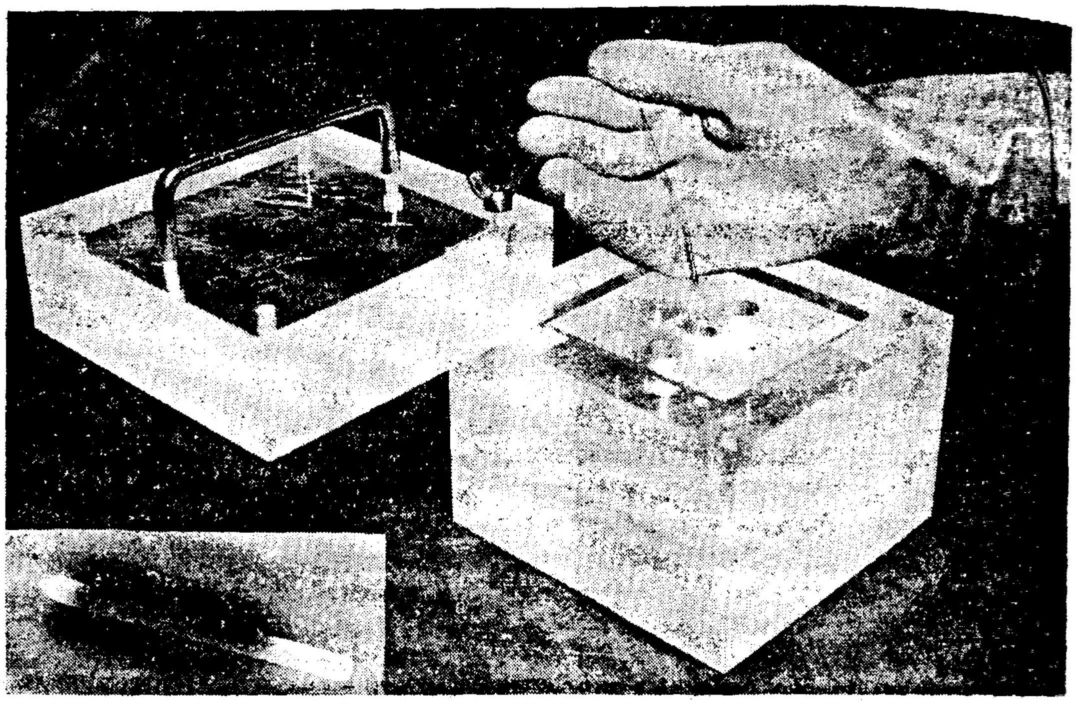
The technology of producing and using cobalt 60 as a heat-producing isotope continues to advance. Cobalt 60 promises to be among the cheapest of the heat producing isotopes. However, because the energy from Co^{60} primarily is a very penetrating gamma ray, its use as a heat source will require heavy shielding. The weight of the latter will probably limit Co^{60} applications to terrestrial or marine uses. These could be for the heat content alone, as in space heater ("pot bellied stove") applications at remote locations—such as the Antarctic—or in undersea laboratories.



World's "Hottest" Cobalt. Photo on *left* shows a cobalt 60 wafer smaller than a dime and which emits 7.5 watts of energy. This wafer, having a record-breaking specific activity of 700 curies per gram, was produced in the Savannah River Plant's high-flux demonstration program during which the highest sustained neutron flux (6.1×10^{15} n/cm^2-sec.) ever attained in a reactor was achieved. Photo on *right* shows a 3-inch long cobalt 60 heat source capsule that produces 260 watts of heat and readily boils the water in the beaker. The capsule, which contains 7,000 curies of cobalt 60, is the first ever made to obtain heat from cobalt. The cobalt 60, which was produced in the high-flux demonstration program, is in the form of 57 wafers, each of which has a specific activity of 120 curies per gram.

Polonium 210

The irradiation process for polonium 210 (Po^{210}) manufacture is well established. Bismuth, which is the target isotope for Po^{210} manufacture, has a very low cross-section and is not readily converted by neutron capture. Thus, large amounts of bismuth are required in a reactor at any one time for polonium 210 production. During 1966, the irradiation being conducted at Savannah River, primarily for curium 244 manufacture (discussed previously), was such that a number of reactor channels were unused, and the opportunity was taken to fill these channels with bismuth. The polonium 210 from this material will be used in process and device development activities at Mound Laboratory.



Californium Needle. By spontaneous fission, californium 252 emits neutrons that may be used for therapeutic purposes. A needle slightly over an inch long has been loaded with 1.4 micrograms of man-made californium 252 by special electrodeposition techniques at the AEC's Savannah River Laboratory and is being used to determine dose distribution in material equivalent to human tissue. In the autoradiograph (*inset photo*) the dark area was produced by radiation from the californium 252 which emits 3.4 million neutrons per second by spontaneous fission. The outline of the needle was obtained by exposing the film to X-rays. It has been proposed that the needle could be placed directly in a malignant tumor. This treatment would expose the tumor to a high concentration of neutrons, particles which have not been thoroughly investigated for cancer therapy in the past because of the difficulty of depositing neutrons specifically in the tumor. Heretofore, too much intervening healthy tissue was exposed. So far, neutron irradiation for cancer treatment has been possible only by placing the patient in close proximity to a nuclear reactor or a cyclotron. Considerable work in this field has been done at the AEC's Brookhaven National Laboratory. The treatment is costly and is limited by the availability of reactors and cyclotrons.

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To meet anticipated requirements for larger quantities of polonium 210, which has a 138-day half-life, for heat source applications, Hanford, Mound, and Savannah River are evaluating processes for the recovery and purification of polonium 210 from irradiated bismuth. Vacuum distillation has been demonstrated to recover relatively pure polonium from bismuth and is expected to make the bismuth immediately available for re-irradiation. However, a special facility would be required for such a process. To meet increased requirements at an earlier date, solvent extraction with diethyl carbitol could be applied in an existing solvent extraction facility to separate polonium from the bulk of the bismuth, with correspondingly reduced total expenditures for the process.

Thulium 170 and 171

Oak Ridge National Laboratory has completed a study of the nuclear reaction cross sections that are important in determining the effective reactor production rates of the thulium 170 and 171 radionuclides. Thulium 170 could be produced by irradiation of naturally occurring monoisotopic thulium 169. Three modes of reactor production of thulium 171 were studied: (*a*) successive neutron captures in thulium isotopes beginning with thulium 169; (*b*) neutron irradiation of isotopically enriched (96%) erbium 170; and (*c*) irradiation of naturally occurring erbium. The study will be extended to determine the practical modes of production for these two radioisotopes, purity of the products, biological shielding requirements, and economic factors relevant to costs of isotopic power fuel forms.

Uranium 233 Recovery

Production of uranium 233 (U^{233}) by irradiation of thoria (ThO_2) continued during the year at both Hanford and Savannah River to supply high-purity uranium 233 for reactor and fuel cycle development needs. For research and development purposes, high purity uranium 233 with a low (4 to 6 parts-per-million) uranium 232 content is desired because its low radioactivity is more conducive to direct handling and fabrication without the use of heavy shielding. Hanford recovered high purity uranium 233 in the Purex plant; Savannah River recovered high purity uranium 233, using a similar process which normally processes highly enriched uranium-aluminum alloy fuels. About 200 kilograms of this high-purity uranium 233 was produced for the Light Water Breeder reactor (LWB) physics critical experiments at the Bettis Atomic Power Laboratory (see Chapter 7—Reactor Development and Technology). Some uranium 233 was transferred to the Oak Ridge National Laboratory research pool for storage and distribution.

FISSION PRODUCTS

Fission products are the nuclear fragments resulting from the splitting of a fissionable atom and constitute the highly radioactive (high-level) wastes from the chemical processing of irradiated ("spent") nuclear fuels. Many of the fission products are radionuclides having potential large-scale application as heat and radiation sources.

Hanford Prime Source

Currently, the prime source for fission-product radioisotopes is the recovery operation conducted at the AEC's Hanford, Wash., production complex; a secondary source could be the Savannah River Plant at Aiken, S.C. Detailed design work is continuing on the Fission Products Conversion and Encapsulation Plant at Hanford which is scheduled to begin a large-scale radioisotope recovery operation as a private commercial enterprise.

During the 1961–1963 period, facilities at Hanford had been modified and adapted for recovering and providing, as selected concentrates, the fission products strontium 90, cesium 137, cerium 144, and promethium 147 [8] that are required by other AEC programs. With the exception of cesium 137, these fission product radioisotopes are recovered from the currently generated high-level chemical processing wastes. The cesium 137 is recovered from stored aged high-level waste solutions. Since the initiation of recoveries in 1960, Hanford has made deliveries of fission products as shown in Table 1.

TABLE 1.—FISSION PRODUCT DELIVERIES, 1961–1966

Fission products delivered to	Kilocuries for CY's	
	1961/1965	1966
Strontium 90		
Oak Ridge National Laboratory	6,200	1,700
Martin Co., Quehanna, Pa	1,244	0
Cesium 137		
Oak Ridge National Laboratory	2,500	1,000
Cerium 144		
Oak Ridge National Laboratory	1,000	0
Promethium 147 (as 2.5-year aged)		
Oak Ridge National Laboratory	59	0
Pacific Northwest Laboratory	309	3,730

[8] See pp. 48–50, "Annual Report to Congress for 1963."

Private Plant Being Designed

Fission product fractions of strontium 90 and rare earths—containing promethium 147—not required for scheduled deliveries, are being accumulated and stored for the decay of objectionable short-lived isotopes in Hanford's B-Plant facilties. These fractions are being accumulated as initial feeds for the Fission Products Conversion and Encapsulation (FPCE) Plant. The FPCE Plant is to be built on leased ground in Hanford's chemical processing areas as a private venture by Isochem Inc.[9] Isochem, as an AEC contractor, also took over the operation of the Government-owned chemical-separations facilities at Hanford at the beginning of 1966. The FPCE Plant, for which an AEC construction permit is now pending, is planned as a facility to obtain specification feeds of strontium 90, cesium 137, and a rare earth fraction from Hanford's waste management operations.

In addition to the fission products already mentioned, the Hanford high-level wastes contain trace amounts, although significant total quantities, of rhodium, palladium, and technetium, an element not found in nature but with chemical properties similar to rhenium. Techniques are being developed to recover and purify these potentially valuable elements.

The AEC's Savannah River operations has developed flowsheets to recover a crude promethium 147 concentrate in both of its irradiated fuel processing plants. The actual process steps would use existing equipment in each plant and could be performed with a minimum of interference to other plant processes. In October, a demonstration run in the Purex plant (F-Canyon) recovered from fresh wastes the equivalent of approximately two megacuries of 2.5-year aged promethium 147 which is being stored in existing tanks. From three to four years' lead time for preparation, concentrate accumulation, and aging for decay of the unwanted promethium 148 would be required for promethium 147 deliveries from Savannah River.

RADIOISOTOPE SALES

To meet the needs of the Government, industry, and science for radioisotopes, AEC facilities are used to produce, or recover in purified form from chemical reprocessing wastes, and package a wide variety of isotopes. The Isotopes Development Center at Oak Ridge serves as the primary sales point for these AEC products. As specific radioisotopes become reasonably available from private commercial producers, the AEC withdraws from the routine production and distribution of those isotopes.

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[9] See p. 81, "Annual Report to Congress for 1965."

Cobalt 60 Sales Increase

During the 11 months ending November 30, 1966, a total of 2,516,978 curies of processed radioisotopes were distributed by Oak Ridge National Laboratory. This represents a 125 percent increase in unit sales over the same 1965 period, mainly from increased sales of cobalt 60 and promethium 147. A total of two million curies of cobalt 60 were sold representing 79 percent of the total curies distributed by ORNL. Significant shipments of cobalt were made to Brookhaven National Laboratory (792,000 curies) for use in its High Intensity Radiation Development Laboratory and to Atomic Energy of Canada Limited (477,000 curies) for re-sale to its commercial customers.

Production and Sales Withdrawals

The AEC withdrew from the routine production and sale of 19 more radioisotopes during the year: antimony 124, arsenic 76, arsenic 77, bromine 82, cadmium 109, cadmium 115, cadmium 115^m, copper 64, gold 198, gold 199, lanthanum 140, mercury 197, mercury 203, molybdenum 99, phosphorus 32, potassium 42, silver 110^m, sodium 24, and sulfur 35. This makes a total of 36 radioisotopes from which the AEC has withdrawn since May 2, 1961, as these isotopes became available from private industry. As a direct result of these withdrawal actions, the number of shipments made by ORNL during the first 11 months of 1966 fell to 5,044 from 7,907 in the same period in 1965, and 10,387 in 1964. The continuing withdrawals resulted in the need for the AEC to increase prices[10] on 13 products to achieve full-cost recovery for the production of cobalt 60 in solution, europium 152, hafnium 181, indium 114, irridium 194, iron 55 and 59 (in combination), osmium 191, rubidium 86, scandium 46, tantalum 182, tungsten 185, yttrium 90, and tritium (hydrogen 3) targets.

Other withdrawals. The AEC also withdrew from supplying the technetium 99^m generator which was developed by Brookhaven National Laboratory, but is now available at reasonable prices from at least five commercial firms.

The AEC had withdrawn from providing encapsulation service to the public for cobalt 60 sources in 1958, but continued to encapsulate its own sources. During 1966, a decision was made to have all cobalt 60 sources used by the AEC laboratories and contractors and other Federal agencies encapsulated by private industry, since competitive commercial service is now available at reasonable prices. As a result of this decision, the Brookhaven shipment mentioned above was commercially encapsulated by the Lockheed-Georgia Co., Marietta, Ga.

[10] A full list of prices is available from the Isotopes Sales Dept., Isotopes Development Center, Oak Ridge National Laboratory, Post Office Box X, Oak Ridge, Tenn. 37831.

Chapter 5

THE NUCLEAR DEFENSE EFFORT

The AEC, in coordination with the Department of Defense (DOD), conducts the necessary research, development, testing, and production essential to the maintenance and improvement of the United States nuclear defense capability.

WEAPONS DEVELOPMENT, PRODUCTION, AND TESTS

During 1966, the AEC (through its three weapons laboratories—Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory, Livermore, and Sandia Laboratory—Albuquerque, N. Mex., and Livermore, Calif.) continued the maintenance of the limited nuclear test ban treaty safeguards,[1] continued the development of devices and improved techniques for underground testing, and continued the development of weapons and components designed to meet DOD requirements.

WEAPONS DEVELOPMENT

The continuing development objective of improving the penetration capability of strategic misssile warheads—by further decreasing warhead vulnerability to nuclear environments generated by antiballistic missile countermeasures—has resulted in modification programs for some warheads in the stockpile. Nuclear tests in 1966 verified laboratory computations and designs for achieving improvements in hardness.

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[1] The four safeguards announced as U.S. national policy by the late President John F. Kennedy and reaffirmed in April 1964 by President Johnson, are: (*1*) continuation of an aggressive underground nuclear weapons test program, (*2*) maintenance of a progressive laboratory program, (*3*) a readiness capability to resume atmospheric tests if they should be essential to national security or if the treaty should be abrogated, and (*4*) the improvement of our capability, within feasible and practical limits, to monitor the terms of the treaty and to detect violations.

Weapons Progress

Weapons tests related to nuclear safety, increased reliability, and increased efficiency were conducted in 1966. Development of improved devices for installation in nuclear weapons to prevent unauthorized employment continued.

The weapons development effort includes overall weapon improvements as well as advancements in individual component design with the resulting technology incorporated into specific weapon systems.

Progressive Laboratory Programs

The AEC weapons laboratories are continuing to function in a healthy and modern environment. The upgrading of facilities—part of one of the test ban treaty safeguards—is progressing as scheduled. Included in the upgrading program are scientific computer complexes at the laboratories which are vital to the development programs. Most projects have been completed with only a few of the larger projects still in the construction phase. The AEC budgets for fiscal years 1966 (ending June 30, 1966) and 1967 (first half ending December 31, 1966) provided for progressive laboratory programs in basic weapons technology and applied nuclear research and development oriented to stated military requirements.

A major facet of the laboratories research and development programs was the design and fabrication of test devices for use in the continuing underground test program at the Nevada Test Site. The laboratories continued to maintain and test their readiness capability to resume atmospheric testing, if authorized, in a minimum reaction time.

The facility improvement program, the continued maintenance of challenging research and development programs in all phases of nuclear technology, and the continuing underground test program have allowed the laboratories to continue to expand the "state-of-the-art" and also to retain and recruit the essential technical staff to conduct the assigned programs.

Nuclear Explosives As a Research Tool

Production of Heavy Elements

On May 5, 1966, a research team from Los Alamos Scientific Laboratory, assisted by Lawrence Radiation Laboratory, Livermore, and Argonne National Laboratory personnel, successfully conducted, as an adjunct to a weapons development event, the Cyclamen experiment.

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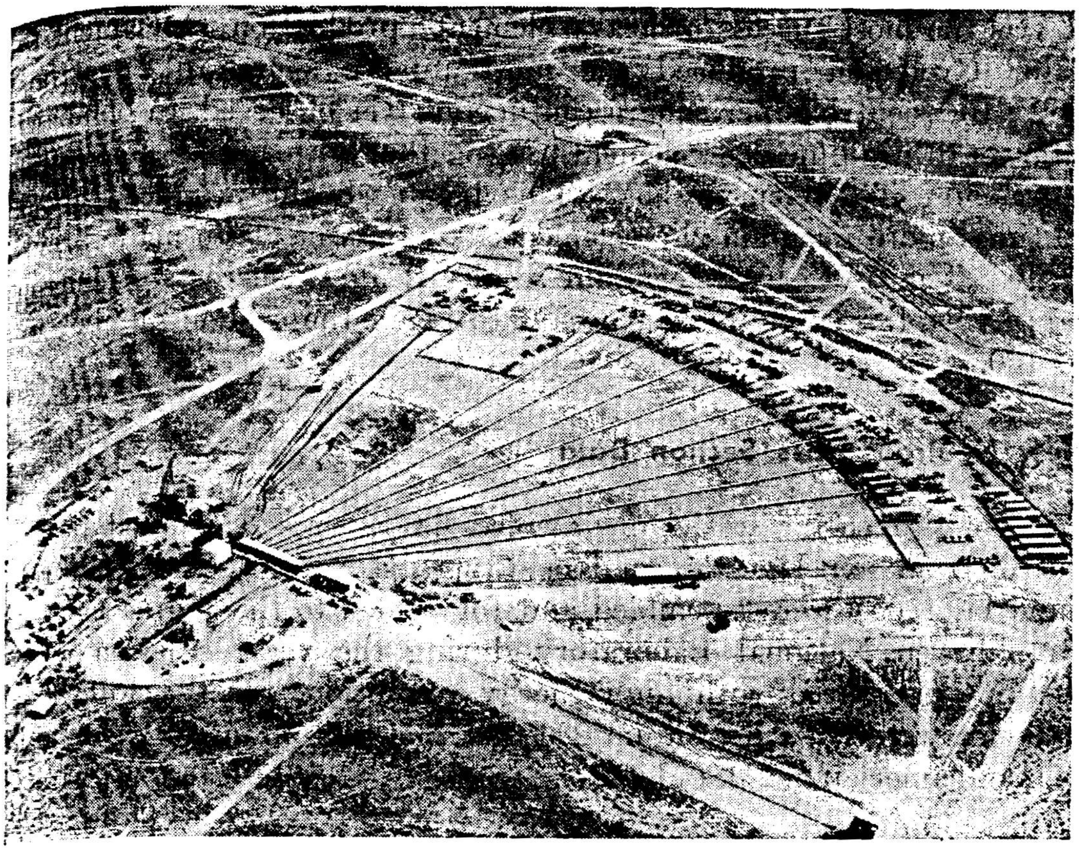

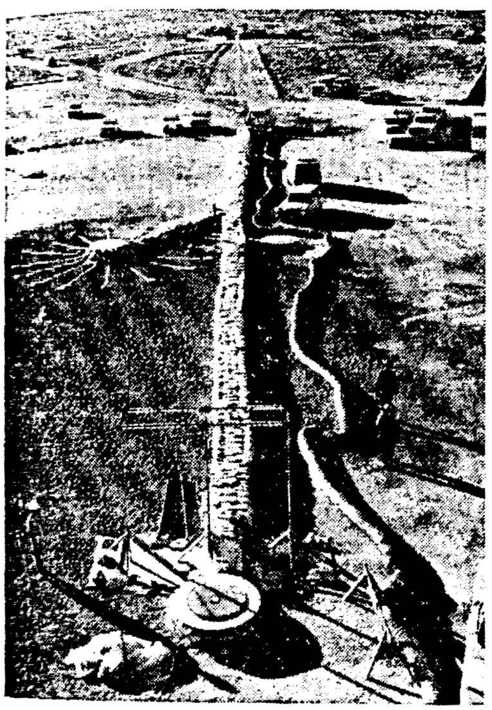

Experimental Array. Nuclear detonations are conducted at the Nevada Test Site not only as a part of the weapons development program, but also to provide needed information and data, *e.g.*, neutron cross-section or time-of-flight measurements, of use in other phases of the atomic energy program. The aerial view *above* shows the complex array of equipment that was used at a multi-purpose nuclear test during the year. The detonation point was hundreds of feet below the convergence of the signal cables; the instruments to record the test results were housed in the trailers to the right. Surface subsidences from two previous detonations are visible—left of center, and upper left of the photo. Photo at *left* shows how sandbags were used to protect cables for a Lawrence Radiation Laboratory, Livermore, electromagnetic add-on experiment during the year. The "snake-like" hose was not a part of the experiment, but was part of an air filtering system to prevent escape of radioactivity during the post-event sample recovery operations.

It was the most successful heavy element [2] production experiment to date. Cyclamen produced the most intense source of neutrons (1.2×10^{25} neutrons per square centimeter) yet observed, to bombard a target of uranium 238 (element 92) together with a small amount of americium 243 (element 95). This bombardment produced about 10 times more fermium 257 (element 100) than has been made previously. This isotope of fermium results from 19 successive neutron captures followed by 8 beta decays to bring the atomic number up to 100.

New Neutron Cross Section Data

A comprehensive set of unclassified fission cross section data deduced from experiments conducted with a weapons test (Petrel, June 11, 1965) were assembled and forwarded to the Sigma Center, Brookhaven National Laboratory during the year. Fission cross sections, measured with high energy resolution, for the following nuclides were listed: uranium 233 and 235, plutonium 239, 240, and 241, and americium 241 and 242.

WEAPONS PRODUCTION

The AEC's production of nuclear weapons during the year, as directed by the President, continued to fulfill the Department of Defense's stated military requirements with no major production problems. The weapons production workload necessary to meet military requirements in 1966 was somewhat below the 1965 level.

Stockpile Improvement

Weapons production activity incorporated several design and technological improvements which contributed significantly to efficiency as well as to simplified maintenance procedures. Modification of the stockpile to incorporate the latest methods for the prevention of unauthorized use of weapons was continued.

Production activities include the fabrication and assembly of new weapons, factory and field modifications of existing weapons, and retirement and disposal of obsolete weapons. In the retirement of obsolete weapons, careful attention has been given to the recovery of re-usable components, both nuclear and nonnuclear, for use in current AEC production of weapons, or for use in research and development

[2] Uranium—element 92—is the heaviest naturally occurring element; all higher-numbered elements are man-made except for the minute amounts of plutonium which occur naturally when neutrons from cosmic radiation are captured in natural uranium 238. Such amounts of plutonium are so small that for all practical purposes, plutonium is considered a man-made element.

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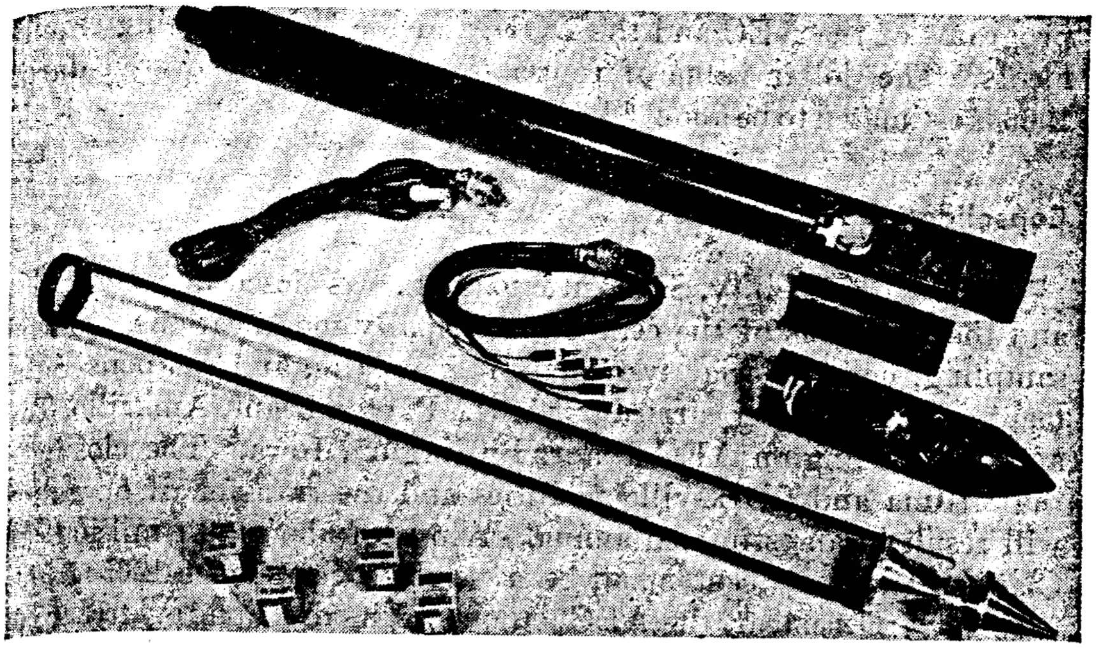
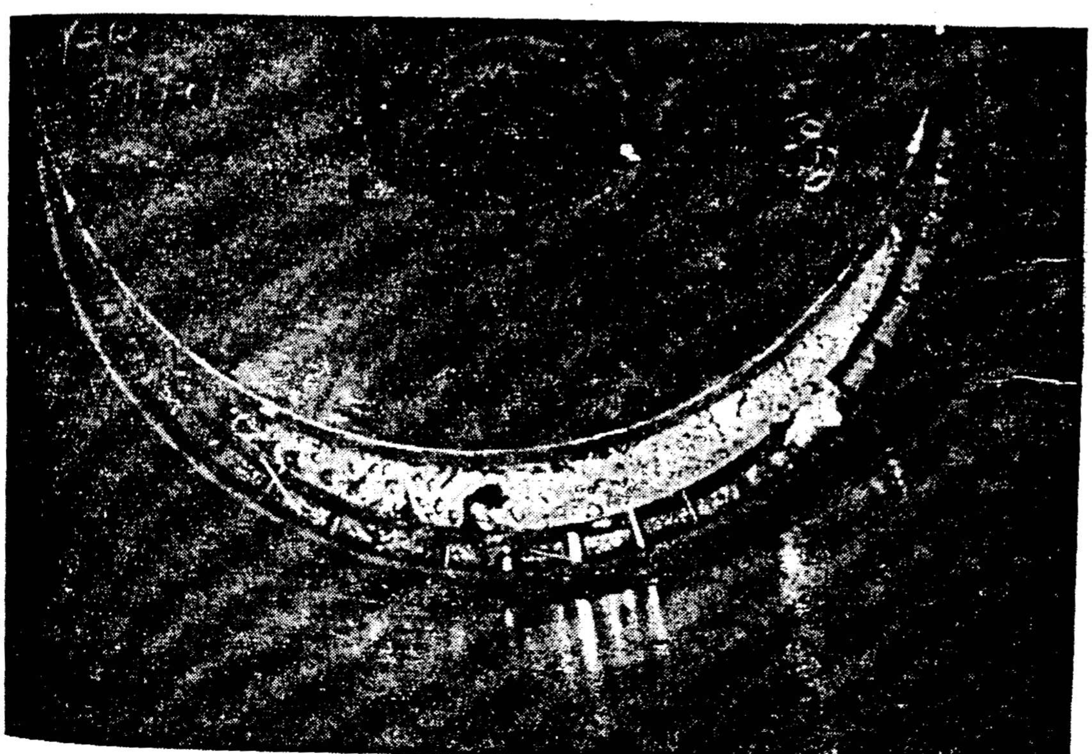


Downhole Camera. Many questions have been raised in the past at the Nevada Test Site as to what is happening down its many drilled detonation holes. To answer these questions a 35mm downhole camera was designed and built by Lawrence Radiation Laboratory, Livermore. The camera—its major components are shown *above*—is unique in design as it is a remotely operable, shutterless type, capable of taking photographs in either horizontal or vertical planes. Coupling a xenon strobe-light with conventional photographic techniques has yielded high resolution photographs in either color or black and white at depths beyond 2,000 feet—the photo *below* was taken at a depth of 1,680 feet. The use of this camera has made significant contributions to pre-shot and post-shot diagnostic efforts at the Nevada Test Site.



programs of the AEC and the DOD, and for DOD training requirements. The dollar value of re-usable components recovered during 1966 is estimated to be about $4.6 million.

Consolidation of Facilities

The Medina Facility, San Antonio, Tex., was closed in early spring, and the functions of the center—principally modifications, stockpile sampling, new material system testing, repairs, and weapons retirement—are now being carried out at the Pantex Plant, Amarillo, Tex., and the Burlington AEC Plant, Burlington, Iowa. The closing of the Medina and Clarksville facilities and the transfer of operations will result in an estimated annual savings of about $3.1 million (the Clarksville, Tenn., center had been closed in September 1965).

In early December, the AEC announced its decision to further consolidate the production complex by reducing certain machining activities at the Kansas City Plant (operated for the AEC by the Bendix Corp.) and, beginning in the spring of 1967, gradually reducing and possibly eliminating the production workload at the South Albuquerque Works (SAW-operated for the AEC by ACF Industries, Inc.).

The decision follows a 2-year study of the weapons production complex to determine the facilities needed to meet continuing weapons production requirements. Annual savings resulting are estimated to range from $6 to $8 million. It is anticipated that these actions will be completed within two years with personnel reductions announced as far in advance as possible.

The plan for reduction and possible phasing-out of the Albuquerque plant includes a program to minimize the local impact. Consideration will be given to such alternatives as transfer or sale of the plant as a going concern—with possibly an AEC base workload—or other arrangements to sell or lease the plant on a special basis designed to meet the local situation and closeout of the plant, if necessary. A task force has been established to coordinate the development and implementation of a plan for disposal of the plant.

Consolidation of Development Work

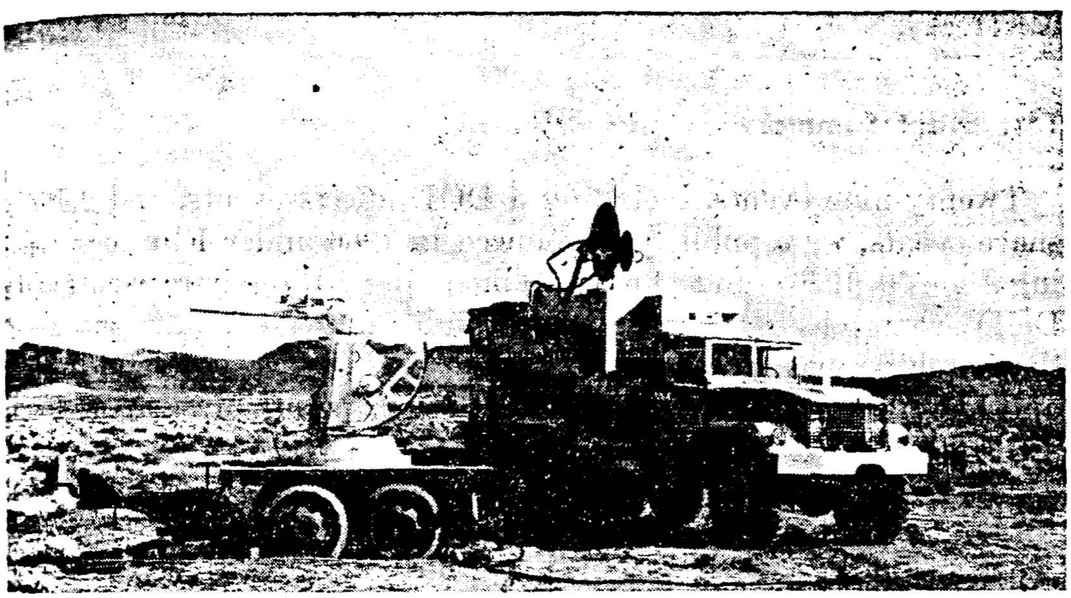
It was announced in late 1965 that neutron generator development work, formerly carried out by General Electric Co. at Milwaukee, Wis., would be consolidated with closely related work at the AEC-owned, GE-operated Pinellas Plant at Clearwater, Fla. The integration of neutron generator development work with production activities was completed in early October.

UNDERGROUND NUCLEAR TESTS

The AEC continued conducting an underground nuclear test program as called for in the first safeguard associated with the limited nuclear test ban treaty. A continuing, comprehensive test program has been conducted since the signing of the limited nuclear test ban treaty by the three principals (U.S., U.K., and U.S.S.R.) on August 5, 1963. As a result of the continuing tests, a unique capability to support a diverse range of full-scale AEC and DOD underground nuclear tests has been developed, maintained, and improved.

Flintlock-Latchkey Series

The current test series called Latchkey commenced on July 1, 1966, and will continue through June 30, 1967. The test series ending on June 30, 1966, was called Flintlock. The combined AEC–DOD test program was developed to pursue those aspects of nuclear technology considered most important to the maintenance of the national security.



"Sky Scanner." An instrument called the "Sky Scanner" has been developed by Lawrence Radiation Laboratory, Livermore, to define and measure the radioactivity in a cloud resulting from seepage or venting which may occur from underground nuclear tests at the Nevada Test Site. This instrument is a tightly collimated scintillation detector mounted on a surplus missile tracking pedestal. Elevation and azimuth control are actuated from the control point located 15 to 20 miles away. Data received by the instrument consist of a TV picture of the collimator sight path, the radiation intensity, and elevation and azimuth angle readouts. All data are transmitted between the instrument and the control point by radio link. Since the radiation detector sees only that activity of a radioactive cloud intercepted by the solid angle of the collimator, cloud dimensions can be defined with a fair degree of accuracy. The total activity in the cloud is estimated by measuring the quantity which is carried by wind currents past a preselected sight path.

The planned events of Latchkey, as approved in principle by the President are grouped in four broad categories: (*a*) AEC weapons and/or device development events: (*b*) DOD nuclear effects events; (*c*) joint AEC–DOD tests designed for research and development on improved detection methods and systems to enhance the U.S. detection capability (Vela program); and (*d*) AEC Plowshare—peaceful uses of nuclear explosives—experiments. Included in the first category are events to further weapons and device developments, investigate concepts and technologies, assure the reliability and safety of nuclear weapons, and investigate nuclear effects on materials and components. Certain nuclear events, with increasing magnitudes of yields from low intermediate (20–200 kt), to intermediate (200 kt-1 megaton), on a step-by-step basis, were planned and conducted in the Pahute Mesa area. The 1964 expansion of NTS operations [3] into the more remote, higher elevations of the Pahute Mesa has led to the drilling of deeper holes to accommodate higher-yield detonations.

Each nuclear event is reviewed and approved in accordance with AEC procedures, and the tests are executed only with the expectation that they can be conducted within the constraints of the limited test ban treaty.

Test Event Summary

Twenty-nine events, including 5 DOD effects events, and 2 Plowshare events, were publicly announced in 1966 under Flintlock (ending June 30, 1966), and 11 events (including 2 Plowshare events and 2 DOD events) have been announced under Latchkey. All but one of the Latchkey events were conducted at the NTS, five of the Flintlock and Latchkey events were conducted in the Pahute Mesa area.

Supplemental Test Site

The AEC has initiated a program to investigate and develop possible locations for a supplemental site in the vicinity of the present Nevada Test Site (NTS) so that the combined facilities available for underground testing will be more flexible and suitable. Initial exploration to determine surface and underground characteristics has begun.

The AEC is also exploring remote areas in Alaska, especially Amchitka Island, to determine the suitability of those areas for possible use in underground nuclear testing. Any use of these areas would not affect those programs now conducted at the AEC's Nevada Test Site.

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[3] See p. 69, "Annual Report to Congress for 1964."

TABLE 1.—ANNOUNCED UNDERGROUND TESTS—1966

Name	Date	Type of yield [1]
Flintlock Series		
Maxwell	January 13	Low.
Lampblack	January 18	Low Intermediate.
Dovekie	January 21	Low.
Plaid	February 3	Low.
Rex [2]	February 24	Low.
Red Hot [3]	March 5	Low.
Finfoot	March 7	Low.
Clymer	March 12	Low.
Purple	March 18	Low.
Templar [4]	March 24	Low.
Lime	April 1	Low.
Stutz	April 6	Low.
Tomato	April 7	Low.
Duryea [2]	April 14	Low Intermediate.
Pin Stripe [3]	April 25	Low.
Traveler	May 4	Low.
Cyclamen	May 5	Low.
Chartreuse [2]	May 6	Low Intermediate.
Tapestry	May 12	Low.
Piranha	May 13	Low Intermediate.
Dumont	May 19	Low Intermediate.
Discus Thrower [3]	May 27	Low.
Pile Driver [3]	June 2	Low Intermediate.
Tan	June 3	Low Intermediate.
Puce	June 10	Low.
Kankakee	June 15	Low Intermediate.
Double Play [3]	June 15	Low.
Vulcan [4]	June 25	Low.
Halfbeak [2]	June 30	Intermediate.
Latchkey Series		
Saxon [4]	July 28	Low.
Rovena	August 10	Low.
Derringer	September 12	Low.
Daiquiri	September 23	Low Intermediate.
Newark	September 29	Low.
Simms [4]	November 5	Low.
Ajax	November 11	Low.
Cerise	November 18	Low.
Sterling [3] [5]	December 3	Low.
New Point [3]	December 13	Low.
Greeley [2]	December 20	Intermediate.

[1] Low yield, less than 20 kt; low intermediate yield, 20 kt to 200 kt; intermediate yield, 200 kt to 1 megaton (Mt).
[2] Conducted in the Pahute Mesa area of NTS.
[3] DOD event conducted with AEC laboratory assistance.
[4] Plowshare (Peaceful Uses of Nuclear Explosives) event.
[5] An underground detection event conducted in Mississippi.

The search in the Alaskan area involves finding sites of suitable geology where certain tests can be conducted with a minimum of local disturbance. The Arctic National Wildlife Range is excluded from this survey.

Surface survey teams working on Amchitka Island will soon be followed by crews drilling exploratory holes if the surface geology makes underground exploration appear desirable.

Individuals employed by the AEC and its contractors, the Department of Defense, and other Government agencies including the U.S. Geological Survey will be involved in the effort.

ATMOSPHERIC TEST READINESS CAPABILITY

The AEC continued to maintain the capability to resume nuclear testing in the test ban treaty prohibited environments (atmosphere, underwater, and in space) should the AEC be directed to test in the event of an abrogation of the treaty by others or in the interest of national security, within a minimum reaction period. This capability was first attained on January 1, 1965.

Summary of Readiness Capability

The readiness capability includes the maintenance of facilities, aircraft, and personnel capabilities in the continental United States and in the Pacific Ocean area (Hawaiian Islands and Johnston Atoll) for launching and diagnosing an atmosphere test series on short notice. The airdrop, missile launch, and diagnostic capabilities are maintained in a state of readiness by conducting full scale and abbreviated non-nuclear exercises in the Pacific area and in the continental United States.[4] Operation Windlass, an overseas exercise during September 1966, re-affirmed the U.S. readiness capability.

Diagnostic Aircraft Utilization

AEC policy permits use of the diagnostic aircraft for other appropriate scientific tasks on a non-interference basis with the readiness program and within current financial limitations. Within these limitations, two scientific expeditions with the aircraft were undertaken in 1966.

Cosmic ray study. A cosmic ray scientific study was conducted in early 1966 using the Sandia and Los Alamos-assigned NC-135 diagnostic aircraft. Flights were made from Roosevelt Roads, Puerto Rico, and Ezeiza Airport, Buenos Aires, Argentina during the period

[4] See pp. 102–103, "Annual Report to Congress for 1965."

of February 10–23. The two aircraft were used to measure simultaneously the distribution and intensities of cosmic rays over wide ranges of latitude, with special emphasis on deviations around the equator.

Preliminary analysis indicated that very good data were obtained on nearly 100 percent of flying time. This was believed to be the first simultaneous airborne recording of cosmic ray activity ever carried out with the aircraft maintaining conjugate positions in the northern and southern hemispheres.

Solar eclipse study. The three weapons laboratories were authorized to use all three diagnostic aircraft for airborne experiments during the total solar eclipse on November 12 in the south Atlantic region. The 1966 eclipse expedition was similar in scope to that which was conducted in 1965.[5] The solar eclipse was observed by the diagnostic aircraft east of Buenos Aires, Argentina, with measurements being made of the sun's corona and other solar and astrophysical phenomena. In addition, Sandia and LASL conducted three Nike-Tomahawk rocket launches, above the atmosphere (about 200 miles), from a site near Rio Grande, Brazil to record X-ray emissions from the sun shortly before and during the eclipse. The rocket accumulation of data will be of direct benefit to the Vela satellite program.

PROJECT VELA

The joint AEC–DOD Project Vela research and development program is conducted to obtain data for developing a system, or systems, to increase the United States' capability to detect, identify, and locate nuclear detonations conducted underground or in space by other nations. The DOD (Advanced Research Projects Agency—ARPA) has the overall programmatic responsibility. The objective is to develop a system or systems capable of adequately monitoring any comprehensive nuclear ban. The Vela program has three subprograms: (*a*) detection of underground nuclear explosions; (*b*) detection, by means of satellites, of nuclear explosions in space; and (*c*) detection of nuclear explosions in space by ground equipment.

VELA UNIFORM PROGRAM

The Vela Uniform Program uses both nuclear and chemical explosions to provide data needed to evaluate: (*a*) the capability to detect underground nuclear tests of various yields and in various media; and (*b*) for studies of seismic wave generation by underground disturb-

[5] See p. 104, "Annual Report to Congress for 1965."

ances and how these waves are affected by different travel paths and geologic environments.

Ground Shock Measurements

Measurements of ground shock accelerations and other effects, and the operation of both short and long-range seismic recording stations, continued in conjunction with underground test events at the Nevada Test Site as a part of the Vela Uniform Program. The DOD has the administrative, funding, and technical responsibility for the program, and the AEC is responsible, in connection with approved nuclear events, for: (*a*) conducting the experiment within the provisions of the limited test ban treaty; (*b*) assuring the public safety; (*c*) construc-

Vela Satellite Hardware. AEC Commissioner Gerald F. Tape (*left*) listens to a description of some of the instruments used in the Vela Satellite Program from Dr. James Coon, Los Alamos Scientific Laboratory group leader. Coon is holding an X-ray detector for a Vela satellite. At *center* is Dr. Raemer Schreiber, LASL technical associate director.

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tion and firing; (*d*) determining the yield and conducting post-shot drilling; and (*e*) instrumenting for close-in measurements.

To date, four underground nuclear events have been conducted under the Vela Uniform Program. The first was Project Shoal, a nuclear detonation of about 12 kt in granite, conducted on October 26, 1963, near Fallon, Nev., to record seismic signals from a nuclear detonation for comparison with signals generated by a naturally occurring earthquake. The second was the October 22, 1964, Salmon event of Project Dribble, a tamped [6] event emplaced in salt at the Tatum Salt Dome, near Hattiesburg, Miss., directed at exploring tamped and decoupling [7] techniques. The third event was the Long Shot event conducted on October 29, 1965, on Amchitka Island in the Aleutian Chain, as an experiment designed to obtain a new set of seismic travel time curves from an underground disturbance in a high earthquake incidence area. The fourth event was Sterling, conducted on December 3, 1966, in Mississippi.

Project Sterling

An exploratory drill-back program through the emplacement casing into the Salmon cavity to establish the feasibility of the re-use of the cavity and emplacement hole was completed in late April and the hole and cavity were determined to be re-usable.

A 350-ton yield nuclear device was detonated in the center of the 110-foot diameter Salmon cavity as Project Sterling. The purpose of this event was to investigate the air-filled cavity concept of seismic decoupling in a "sprung" (detonation produced) cavity. This experiment was completely contained.

The theory of "decoupling" the explosive energy from a surrounding salt mass, and thereby reducing the earth shock or seismic signal, has been demonstrated by experiments conducted with chemical high explosives. The decoupling was accomplished by placing the explosive charges in the center of mined spherical cavities before firing them. The energy transmitted to the walls of the spheres ranged from $\frac{1}{100}$th to $\frac{1}{300}$th that transmitted when the same amount of explosive was tightly confined by the surrounding medium. However, less is known about the decoupling effects of a nuclear explosion at the center of a large sphere created by a previous detonation, and the main purpose of Project Sterling was to obtain information on such effects.

[6] *Tamped* is the placing of an explosive device underground in direct contact with the medium in which it will be fired so that the shock and earth movement generated by the explosion will be directly transferred by close physical coupling to the medium.

[7] *Decoupling* is the use of an underground cavity as an explosion site to reduce the transference of the explosive energy and hence the amount of shock and earth movement imparted to the surrounding medium, thus possibly concealing the true magnitude of the explosion or reducing the effects of the explosion below the detection capabilities of a detection system.

The difference in effects would stem from the fact that the walls of mined cavities are strong and relatively undisturbed, while explosion-formed cavities such as the Salmon cavity have walls that are strongly deformed and minutely fractured. An understanding of decoupling, as a possible concealment technique, would be important in relation to a more restrictive test ban treaty.

Preliminary analysis of data shows that decoupling ratios were in the vicinity of 200 for frequencies of one cycle per second and lower, and in the vicinity of 100 for frequencies of 10 cycles per second and higher. It is expected that all data will have been analyzed by April 1967.

Unmanned Seismic Observatory (USO)

A prototype USO, developed by Sandia Laboratory, was installed in a 90-foot borehole in late April near Fairbanks, Alaska, to evaluate the effects of permafrost on the observatory. It is planned that the USO will be evaluated for a 12-month period in the permafrost environment. The unit was tested for about 2 months at an Albuquerque site before being shipped to Alaska for further evaluation in an arctic environment. A second USO was emplaced during mid-July in a 200-foot deep hole at the Uinta Basin Observatory near Vernal, Utah for evaluation over a similar period. A third unit was emplaced in a hole 169 feet deep at the south edge of Sandia Base, Albuquerque, during September. This installation will be used as a test facility for evaluating possible modification and improvements to the USO systems.

The prototype USO's were built for DOD's Advanced Research Projects Agency by Sandia to increase the U.S. capability to detect, identify, and locate underground nuclear explosions. They will operate unattended for up to 120 days with a 98 percent reliability and consist of three packages: (*a*) a down-hole unit consisting of three short-period seismometers and three long-period seismometers; (*b*) an electronic package including logics, tape recorder, timing system, etc.; and (*c*) a thermoelectric power supply.

VELA SATELLITE PROGRAM

The AEC continued to participate in the joint DOD-AEC Vela Satellite Program. As a part of the program, a research and development effort is being conducted by Sandia and Los Alamos Scientific Laboratory to develop the means for detection of nuclear explosion phenomena in space through satellite-based instruments and detectors.

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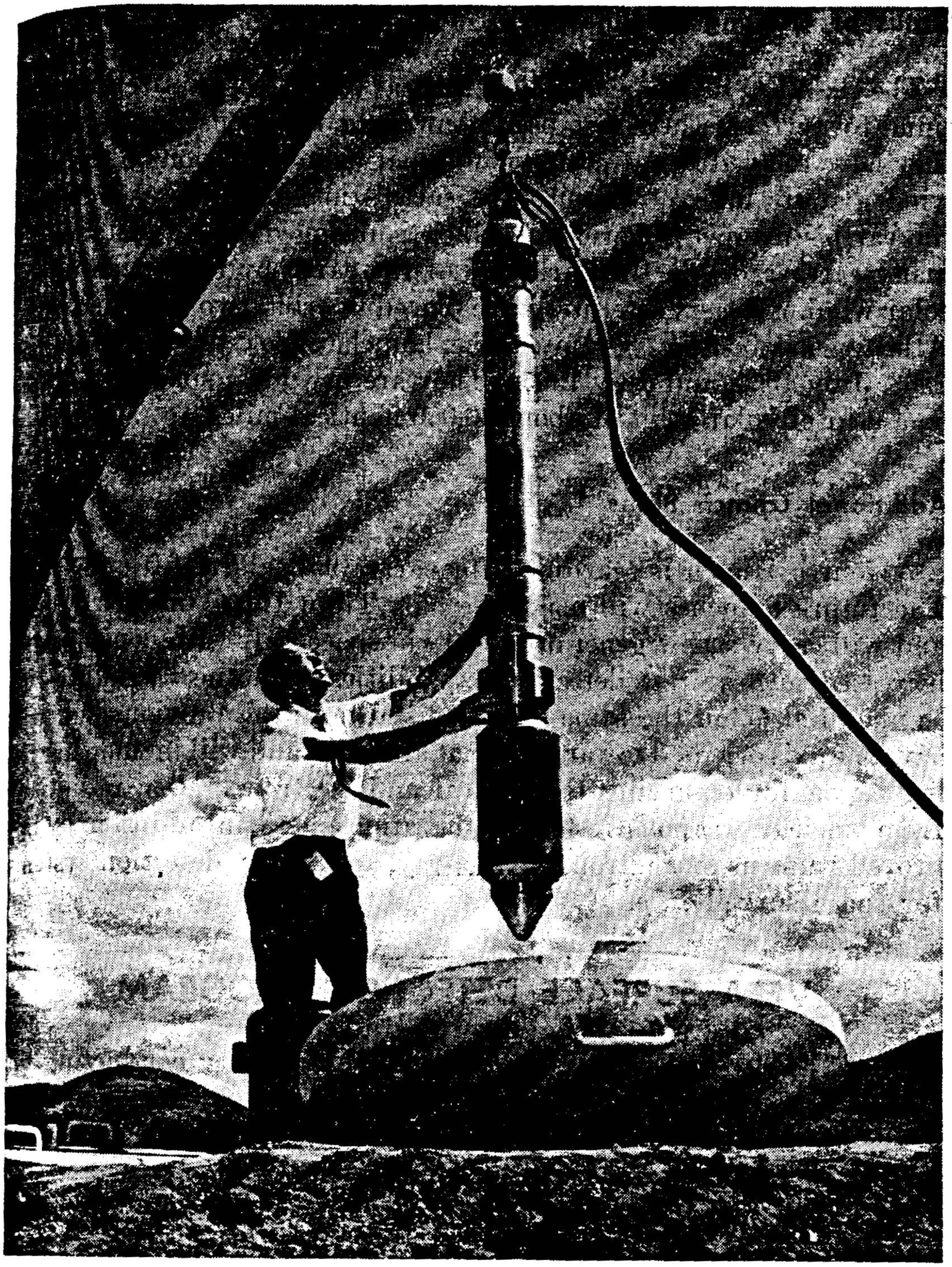


Unmanned Seismic Observatory. The borehole package for an unmanned seismic observatory (USO) was emplaced in a test hole at Sandia Base in April 1966. The location is near the U.S. Coast and Geodetic Survey's seismological laboratory south of Albuquerque. The unit was later emplaced in Alaska for testing in an Arctic environment. The USO, a prototype designed to operate unattended for 120 days with 98 percent reliability, was developed at Sandia Laboratory as part of the Vela Uniform Program for detecting, locating, and identifying underground nuclear detonations. The observatory's most significant feature is its ability to record reliable, precisely timed seismic data while operating unattended in a variety of environments.

Status of Orbiting Satellites

The six AEC-instrumented Vela nuclear test detection satellites continue to perform their test ban monitoring functions. In addition, they have relayed back to earth new scientific information on the solar wind and its interaction with the earth's magnetosphere, including the earth's magnetospheric tail which is dragged out to distances of many earth radii on the dark side of the earth by the action of the solar wind. The six satellites were placed in orbit, two at a time using Atlas-Agena booster systems. The launches took place in October 1963, July 1964, and July 1965. They are in widely spaced positions on a near circular orbit of about 60,000 nautical miles.

Additional Launch Plans

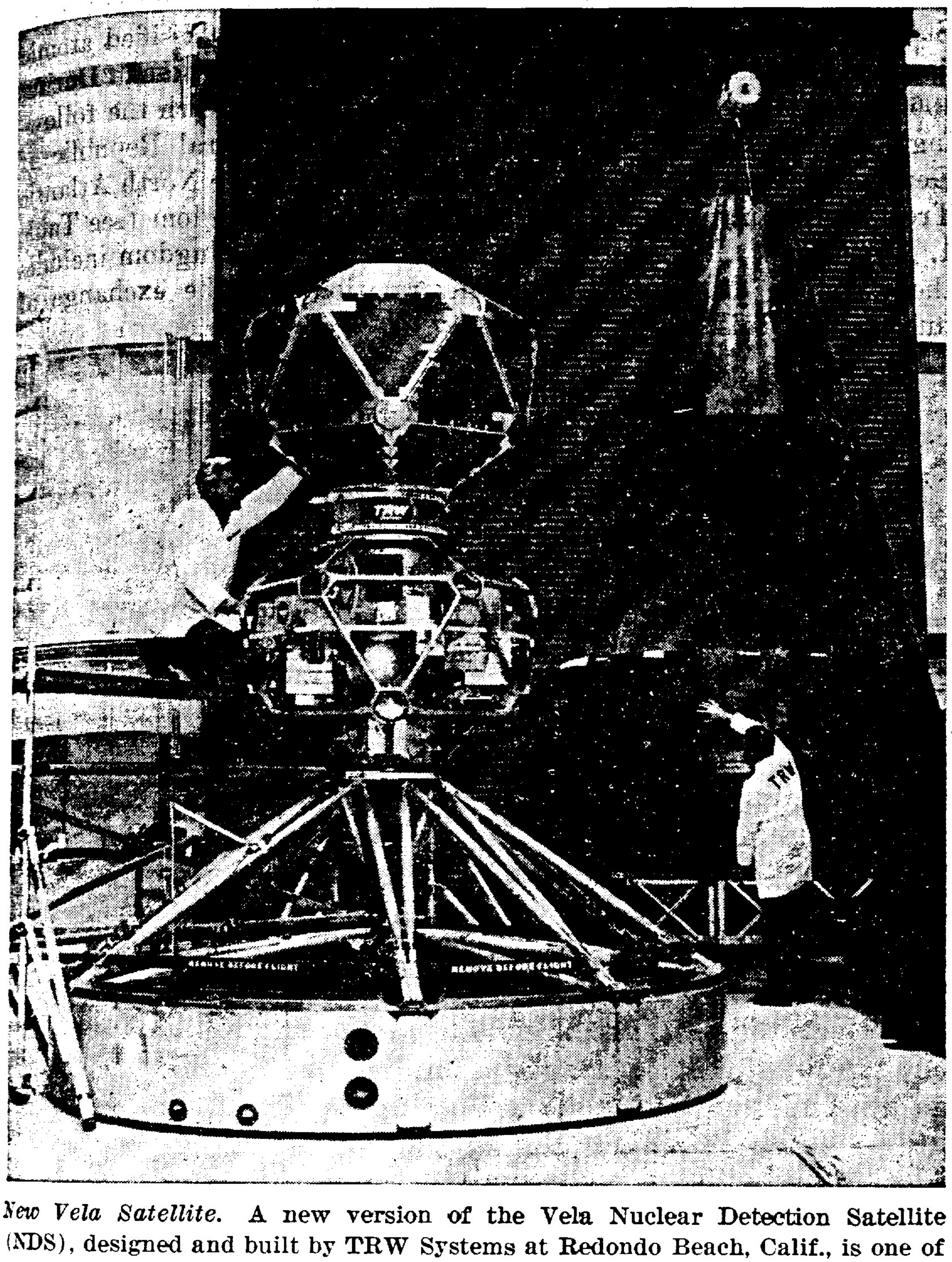
A fourth launch is scheduled for early 1967, and a fifth for 1968. The future launches will make use of a Titan III C booster system, and will carry a new generation of twin spacecraft with considerably increased nuclear test detection capabilities. The new satellites, to be placed at about the same orbital distance as the previous six, will have one axis oriented toward earth at all times, and will include instrumentation for observing the optical and electromagnetic radiations from nuclear weapons tested in the atmosphere in addition to improved versions of neutron, gamma-ray, and X-ray detection systems for space surveillance.

VELA SURFACE DETECTION PROGRAM

The AEC, with Los Alamos Scientific Laboratory conducting the research and development, has continued to participate with the DOD in the joint program of ground-based detection of nuclear explosions in space. The program is directed primarily on the air fluorescence detection method which is based on the measurement of the fluorescent light produced in nitrogen when air at high altitude is bombarded by X-rays from a nuclear explosion.

Data analysis on the 1965 lightning summer study is proceeding well. This study was an experimental program at LASL to investigate background interference produced by lightning, particularly as it affects air fluorescence and electromagnetic pulse (EMP) detection systems. Joint AEC-DOD analysis of data to date has shown that there are certain relationships between the features of lightning-produced EMP and fluorescence signals which will be helpful in associating the fluorescence signals with lightning. Studies of the correlation between air fluorescence and EMP signals will continue.

LASL is assembling an all-sky system using a 5-inch diameter lens (versus the 2-inch diameter lens in present systems) with improved optics in the hope of obtaining greater detection ranges under field conditions.



New Vela Satellite. A new version of the Vela Nuclear Detection Satellite (NDS), designed and built by TRW Systems at Redondo Beach, Calif., is one of two scheduled to be launched in tandem early in 1967. Unlike the six predecessors from three previous launches which are now orbiting the earth and returning valuable data on natural nuclear activity in space, the new NDS's will be larger and heavier. It will weigh 730 pounds *vs.* 420 for the previous satellites; the payload (produced by Los Alamos Scientific Laboratory and Sandia Corp.) will weigh 145 pounds *vs.* 90; it will have 26 sides rather than 20 and will be only a few inches larger in diameter (57 *vs.* 54 inches). Shown *above* is one of the NDS's undergoing preparations for a vibration test that simulates the effects of a Titan 3C missile launch.

MUTUAL DEFENSE AGREEMENTS

Under the provisions of the Atomic Energy Act of 1954, as amended, the President may authorize the United States to cooperate with another nation or a regional defense organization in which the United States is a participant and to communicate certain classified atomic data as is determined necessary for mutual defense purposes. During 1966, there were mutual defense agreements in effect with the following: Australia, Canada, Belgium, France, the Federal Republic of Germany, Greece, The Netherlands, Turkey, Italy, the North Atlantic Treaty Organization (NATO), and the United Kingdom (see Table 1, Appendix 7). The agreement with the United Kingdom includes the exchange of weapon design information and the exchange of nuclear materials.

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STATUS OF CURRENT RESEARCH

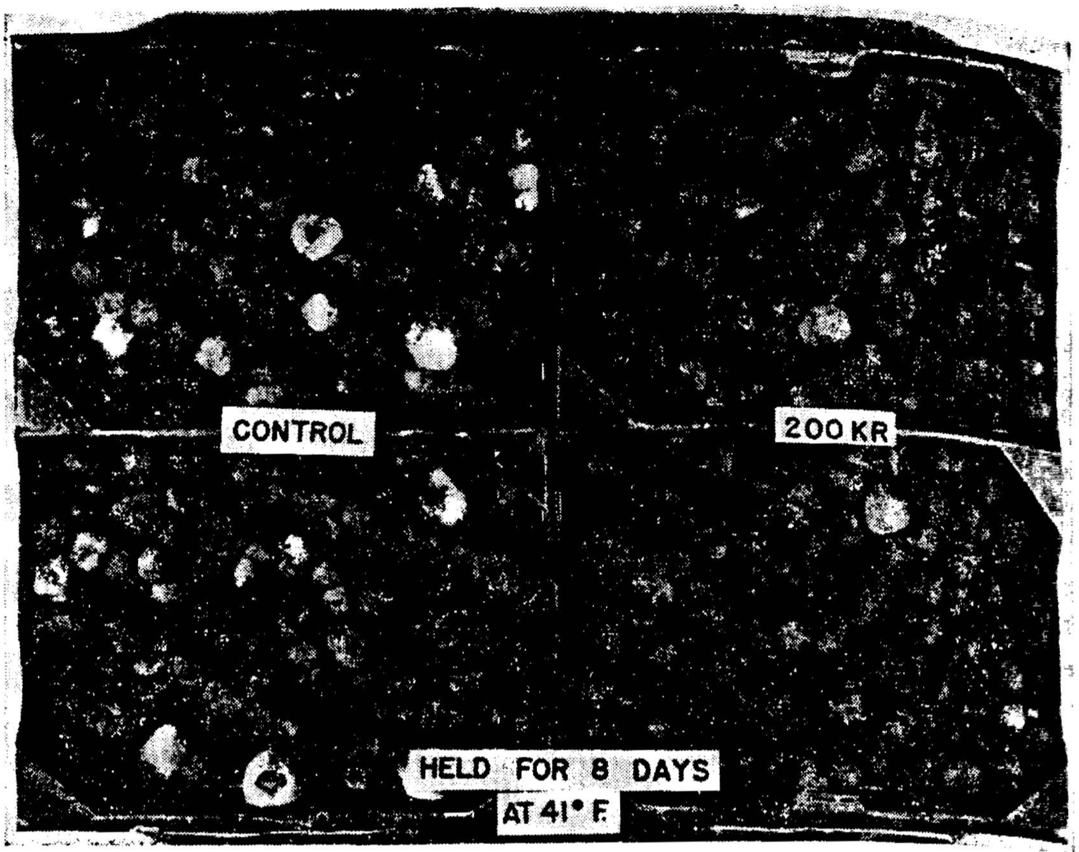
Research results from work under the AEC program continue to offer an optimistic outlook for the use of radiation for commercial processing of several kinds of fresh fish and fruits. The ultimate commercialization of these processes, however, depends upon clearance of such foods for human consumption by the Food and Drug Administration (FDA). Efficacy studies on six species of fish, petitioned to the FDA in September 1965, were completed by the end of November 1966. It is anticipated that some decisions on the clearance of one or more of the fish—cod, flounder, haddock, ocean perch, pollack, and sole will be made in 1967. A significant step during the past year was the submission to the FDA of a petition for clearance of radiation processed strawberries in May. Irradiation processing gives the fruit a two-week shelf-life, generally double that of unprocessed strawberries.

Fish Studies Expanded

During the past year, investigations on radiation processing of fish, which had previously been on a laboratory scale, were expanded to include the effects of commercial handling, shipping, and storing. Haddock fillets were commercially packed, given a dose of 250,000 *rad* of radiation, packed in ice along with suitable unirradiated controls, and shipped from Gloucester, Mass., to Seattle, Wash., for evaluation. The irradiated fish had a 17-day storage life while the non-irradiated controls were acceptable up to 11 days. These tests are now being expanded in conjunction with the fish industry. Currently, 10 large food chains—with over 8,000 retail outlets—are participating in this evaluation program through use of their shipping and storage facilities.

New Technique for Fruit

Textural damage caused by the levels of radiation required for effective rot and mold control has been a major problem in the irradiation of many soft fruits—for example, peaches and nectarines. Recent work has demonstrated that a combination hot-water dip plus a radiation dose one-half of that previously required to do the job yields equally effective control without textural damage. This new technique is important because it will permit an extended shelf-life due to reduction in spoilage for these relatively expensive foods. Another technique recently applied to table-quality cherries is the use of a calcium chloride dip prior to irradiation. Unfortunately,



Pasteurized Strawberries and Fish. Normally, strawberries can be kept in storage from 7 to 10 days before they begin to spoil. After being pasteurized by irradiation, their shelf-life is extended to about 2 weeks—an economic factor of interest to fruit marketers since it doubles their store shelf-life. In photo *above*, the fresh-appearing strawberries on the *right* were processed with 200,000 *rads* (200 KR) of cobalt 60 gamma irradiation at the University of California's Davis campus; the moldy fruit on the *left* was not irradiated. During May, the AEC submitted a petition to the U.S. Food and Drug Administration (FDA) for approval of commercial sale of irradiation-processed strawberries. The process does not make the strawberries radioactive, nor does it detract from their taste. At *left*, a Bureau of Commercial Fisheries, Gloucester, Mass., technician compares samples of cooked pollock—one sample preserved by irradiation, the other not—to evaluate their taste. The AEC is seeking FDA clearance for human consumption of six species of ocean fish.

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progress in this area is limited by the seasonal availability of only a few weeks per year for many fruits.

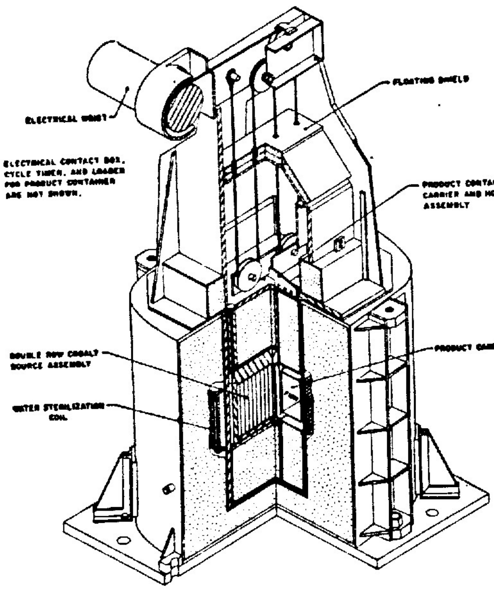
Work at the University of Hawaii indicates a three- to four-day shelf-life extension in papayas subjected to a radiation dose of 75,000 *rad* when coupled with the hot-water treatment. Part of the food was shipped to the University of California's Davis facility for evaluation. Investigators at the University of Florida, Gainesville, have found that rot in mangoes can be controlled with the proper radiation dose.

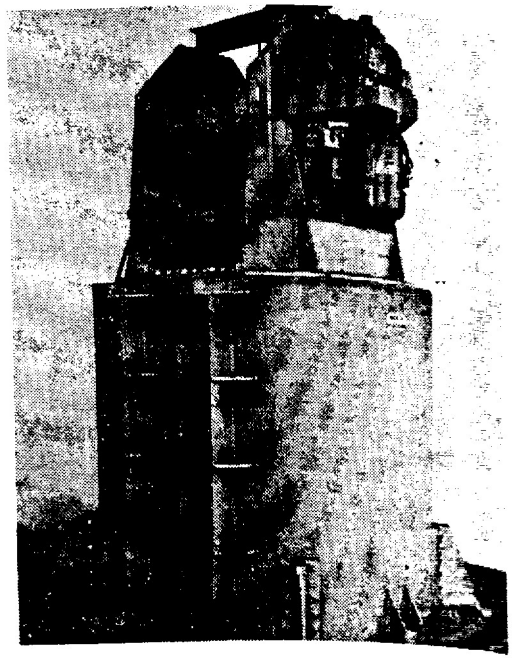
Shelf-Life of Tomatoes Extended

Results of two years of work at the University of California (Davis) with tomatoes irradiated at the "pink" to "full-ripe" stage demonstrate a shelf-life extension of 8 to 15 days. These results differ appreciably from earlier work in which unsuccessful attempts were made to delay ripening of green tomatoes and have special significance when it is recognized that the present trend in the United States is to pick tomatoes in the "pink" stage. Tomatoes harvested at the "pink" to "full-ripe" stage offer a better quality fruit than tomatoes picked green and allowed to ripen during the period of distribution and marketing. The potential of this application is interesting on an economic basis, since fresh tomatoes are a large-volume vegetable commodity in the United States.

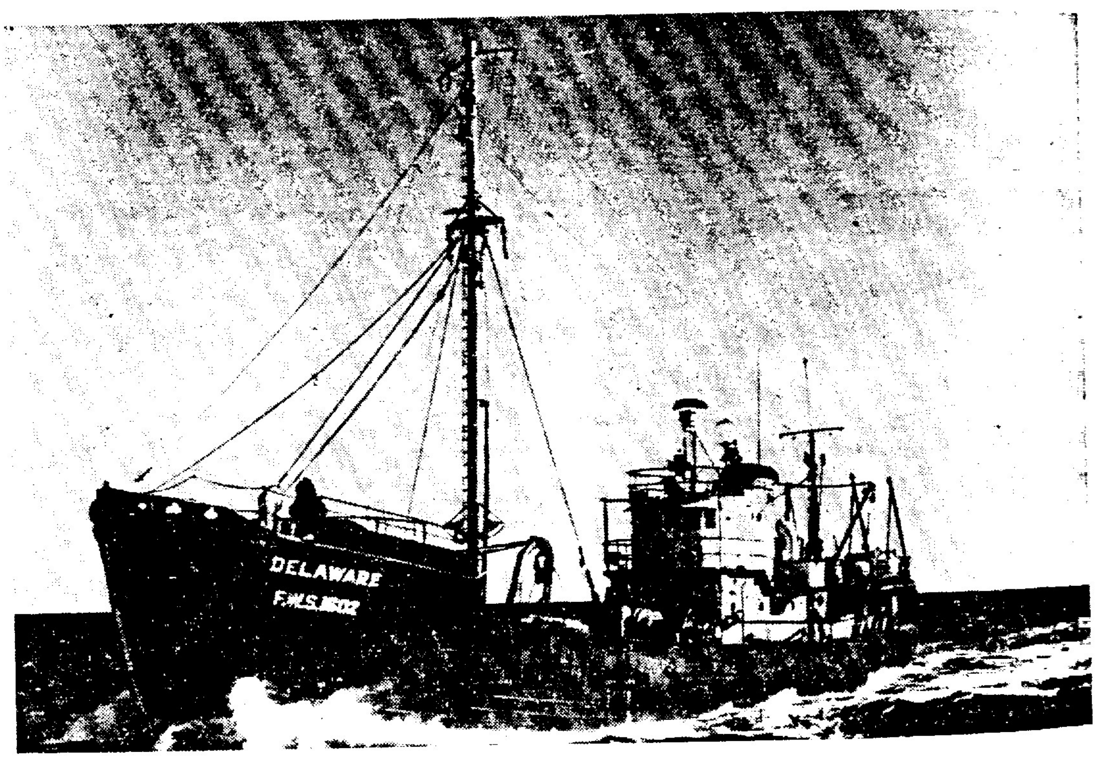
Economic Advantages Shown

Technology for both fish and fruits has developed to a point where a detailed analysis can be made to determine the relative costs and economic benefits of radiation processing of selected foods. This analysis of the potential input into the economy of selected food irradiation processes has been completed by Daniel Yankelovich, Inc., New York City. The results show favorable economic advantages for New England finfish and Hawaiian fruit. The screening criteria developed in the study also indicate that certain products—tomatoes and peaches, for example—should be studied further for possible market development. In the case of finfish assuming commercialization by 1970, reduced spoilage and short-buying benefits alone would provide net discounted benefits to the economy (after all government and private costs) in the order of $10 million by 1980. This figure is based on no increase in the *per capita* consumption of New England finfish. Under reasonable assumptions of market expansion in the midwest and conservative valuation of benefits, the net benefits could double.





On-Ship Irradiator. **The feasibility of irradiating fish as a means of extending the commercial shelf-life has been demonstrated and the Food and Drug Administration has been petitioned to approve six species of irradiation-processed fish for human consumption. Although the capacity of on-ship irradiators is somewhat less than the land-based facilities, they do make it possible to irradiate marine product immediately after catch. This permits extended storage at relatively low radiation doses. Diagram, *left above*, shows the major components of the 17-ton, cobalt 60 fish irradiation units now in demonstration operation aboard two U.S. Department of Interior trawlers. Photo, *right above*, shows a unit of the type installed aboard the trawler Delaware shown *below* which operates out of Gloucester, Mass.**



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Chapter 11

THE PLOWSHARE PROGRAM

Private industry showed increasing interest in underground nuclear explosion engineering techniques for natural resources development and management during the year. A milestone was achieved in this area when negotiations were started between the Government and El Paso Natural Gas Co., El Paso, Tex., for the first joint industry-Government Plowshare experiment, Project Gasbuggy. Nuclear experiments and related studies were conducted during the year to support the continuing Plowshare excavation and scientific programs.

NATURAL RESOURCES DEVELOPMENT

The United States Bureau of Mines (USBM) has estimated there are 2 trillion barrels of oil locked in oilshale formations in Colorado, Utah, and Wyoming that await development of economic techniques for recovery. Also, in the Rocky Mountain States over 300 trillion cubic feet of natural gas is estimated to be in formations of low permeability which are not amenable to economic exploitation by existing means. As discussed below, Plowshare program investigations offer the possibility that nuclear explosives detonated deep in the earth may be the basis for developing new techniques to recover such oil and gas, as well as other natural resources, economically, and more completely.

PROJECTS AND STUDIES

At year's end, with site preparation for Project Gasbuggy underway, three other possible projects involving recovery or storage of natural resources were under study.

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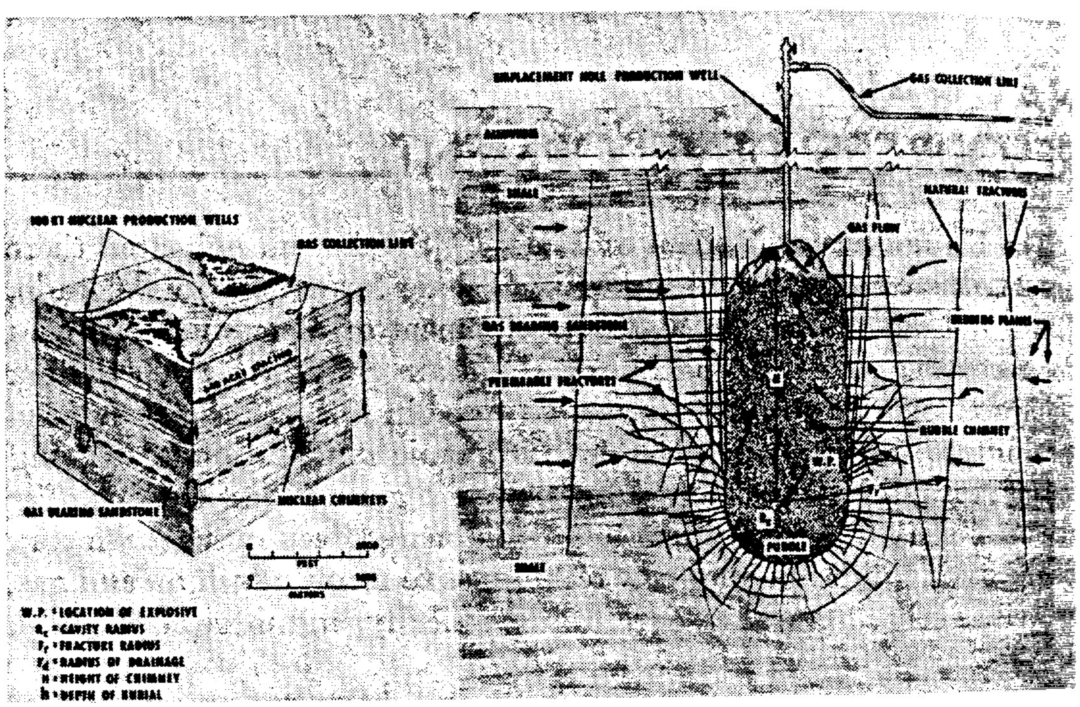
Natural Gas Stimulation

Natural gas is produced commercially from underground reservoirs of permeable rock in which the gas has been trapped. Normally, when a well as drilled into the reservoir rock, natural pressure causes the gas to flow freely into the well from the pores in the rock. In this way, a single well can drain the gas from a large volume of reservoir rock at a rate fast enough to be economically worthwhile.

In many areas in the western United States and Canada, however, natural gas is found in reservoir rock of such low permeability that the gas cannot be produced economically from a normal well. The trapped gas, if it flows at all, does not flow freely enough into the well to give a useful rate of production. Nuclear explosions may be used to increase, or stimulate, the production of gas from such tight reservoirs. In the proposed method, nuclear explosions would be set off in the reservoir rock to create large zones of fractured and broken rock into which the gas could flow more freely.

The Green River Basin in Wyoming, the Piceance Creek Basin in Colorado, and the San Juan Basin in New Mexico and Colorado are the most prominent of the sedimentary basins in the Rocky Mountain



Gas Reservoir Stimulation. In many areas, relatively impermeable rock prevents the economical recovery of natural gas by conventional means. The Lawrence Radiation Laboratory, Livermore, drawings show how nuclear explosives might be used to enhance the recovery of gas from impermeable rock by creating large "chimneys" into which the gas can flow from the surrounding fractured rock. Site preparation has begun in the San Juan Basin, in the northwestern area of New Mexico, for Project Gasbuggy—the first experiment to develop such a peaceful use for nuclear explosives.

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[1] See pp. 193–194, "Anr

states containing gas-bearing reservoirs of low permeability with sufficient thickness to warrant consideration for nuclear stimulation. In addition, areas in western Canada and in parts of Kansas, Oklahoma, and Texas, may also be amenable to this technique. If Project Gasbuggy, the first nuclear gas stimulation experiment, and subsequent experiments show the technique to be feasible, the Nation's recoverable natural gas reserves will be greatly increased.

Project Gasbuggy

Gasbuggy is the first of several experiments to evaluate the use of completely contained nuclear explosions for increasing productivity of natural gas in formations of low permeability. The project is being conducted jointly by the El Paso Natural Gas Co., the USBM, and the AEC. The project resulted from an 18-month feasibility study by representatives of the three organizations, following which El Paso made a proposal to the AEC in 1965 to carry out such an experiment as a jointly sponsored venture.[1]

Initial site preparations have begun in the San Juan Basin, about 55 miles east of Farmington, N. Mex. The first phase involves drilling two wells to measure pre-shot gas production and to obtain additional geological, geophysical, and hydrological information required to establish the pre-shot characteristics of the site and the gas formation to be stimulated. The pre-shot measurements will be used as a basis for evaluating the post-shot results, including increases in gas production.

Radioactive Contamination of the Gas

In the stimulation of gas production with nuclear explosions, the possible concentration of radioactive isotopes in the natural gas produced must be carefully considered. It is known that after 6 to 12 months the short-lived radioactive isotopes will have decayed to acceptable levels, leaving essentially only longer-lived krypton 85 (10-year half-life) and tritium (hydrogen 3) (12-year half-life). Laboratory studies are now being conducted by the U.S. Bureau of Mines and Lawrence Radiation Laboratory, Livermore, to determine the best methods of reducing the concentrations of these two products in the gas produced. Actual concentrations and the effectiveness of control measures will be verified in Project Gasbuggy and other field experiments.

[1] See pp. 193–194, "Annual Report to Congress for 1965."

Other Gas Stimulation Proposals

In the latter half of the year, the AEC received two additional proposals from industry to join in cooperative experiments to stimulate natural gas reservoirs using nuclear explosives. One proposal, named Dragon Trail, was submitted by the Continental Oil Co., Houston, Tex., together with CER Geonuclear Corp.,[2] Las Vegas, Nev.; the other, named Rulison, by the Austral Oil Co., Houston, Tex., and CER Geonuclear Corp. Both proposals involve sites in western Colorado for the experiments. The AEC is currently conducting a comprehensive review and evaluation of these proposals as possible gas stimulation experiments which would be based on and extend the Gasbuggy results.

Recovery From Oil Shale

A recent theoretical study at Lawrence Radiation Laboratory, Livermore (LRL–L) examined the problem of extracting oil from the broken oil shale rock in the "chimney" created by an underground nuclear explosion. Results of the study suggest that a large part of the shale oil, including that in chunks of shale as large as several feet across, can be removed by igniting the broken shale and by maintaining combustion with air supplied to the chimney through drill holes—a process known as "retorting". Heat from the burning front would decompose the solid hydrocarbons in the shale to produce liquid oil, which would collect in the lower portion of the chimney. The oil could then be removed through drainage wells and pumped to the surface.

50–70 Percent Recovery Potential

The proposed nuclear-chimney "retorting" system may use temperatures considerably lower (750° F.) than those in most previously suggested retorting schemes, and thus, could require a lower pressure level of forced air with resultant lower compressor costs. It is estimated that 12 to 18 months would be required to retort completely the broken oil shale in a chimney formed by a 100-kt nuclear explosion. Recovery of 50- to 70-percent of the oil is expected.

Results of the LRL–L theoretical study are in excellent agreement with experiments being conducted at the U.S. Bureau of Mines (USBM), Petroleum Research Center, Laramie, Wyo., in which frag-

[2] In 1965, three firms—the Continental Oil Co., Edgerton, Germeshausen and Grier, Inc. (now formally known as EG&G, Inc.), and Reynolds Electric Co.—formed CER Geonuclear, Inc., to provide a complete "Plowshare Service" to interested firms; see p. 37, "Annual Report to Congress for 1965."

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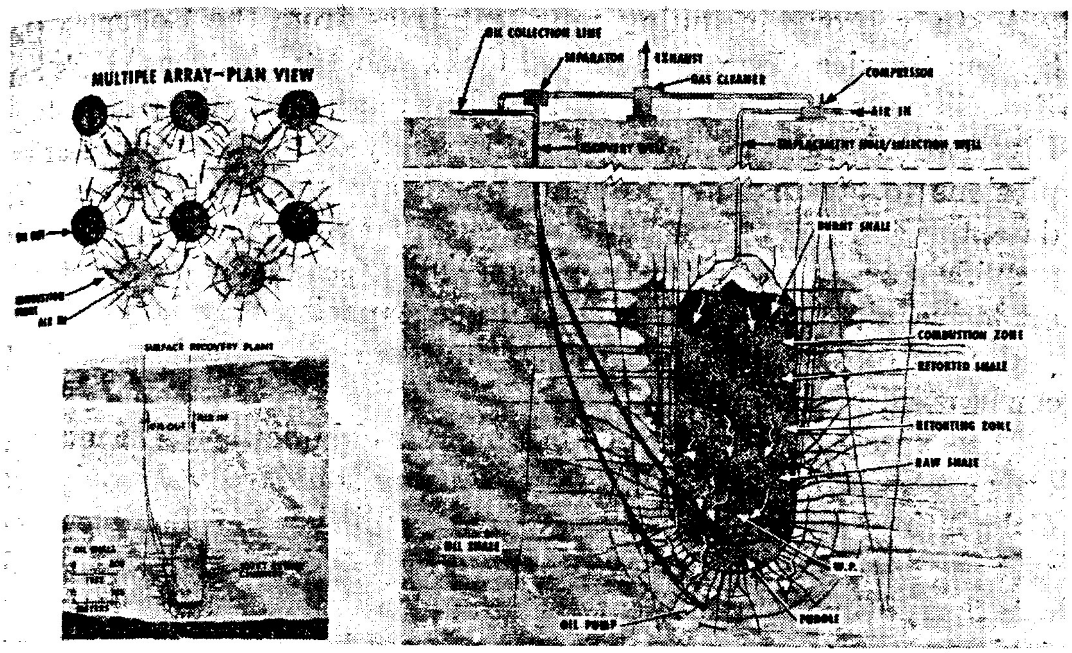
ments of oil shale in the range of sizes anticipated in the nuclear-chimney were retorted in a 6-foot-diameter, 12-foot-high vessel.

It has been estimated that the Piceance Basin in western Colorado contains 320 billion barrels of oil in shale formations of 500 feet or thicker, with an average oil content of 25 gallons per ton. A successful nuclear-chimney retorting system would be a way of recovering at least half of this reserve, or 160 billion barrels.

Proposed Oil Shale Experiment

Twenty-four domestic oil and allied companies have joined with the CER Geonuclear Corp., to consider making a proposal to the USBM and AEC to conduct a joint nuclear explosion experiment in oil shale. The first step will be to undertake a joint Government-industry feasibility study including the companies, AEC, and the USBM. Such a study would include the development of a technical concept by LRL–L for an experiment to test the use of an underground nuclear explosion

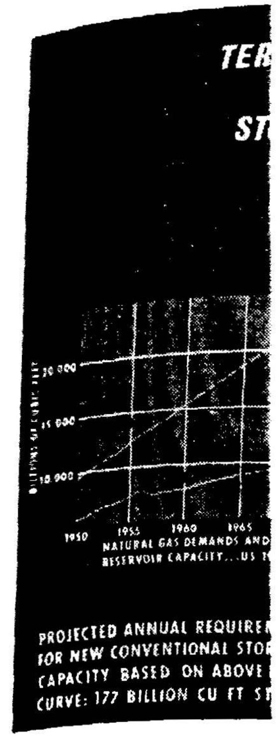


Retorting of Oil Shale. Presently, the Nation's oil reserves take into account only the pools of liquid oil from which the oil can be recovered by conventional wells. However, great quantities of oil are "locked" in deep underground oil shale formations. By breaking this rock and heating it, decomposition occurs and oil is produced. A joint study by the AEC and U.S. Bureau of Mines indicates that it may be economically and technically feasible to use nuclear explosions to break up the oil shale. In this approach—as envisioned in the Lawrence Radiation Laboratory, Livermore, drawings—the broken oil shale rock would be ignited, and burning maintained by forced air injection. The oil produced would be pumped to the surface. A group of over 20 oil companies has indicated an interest in conducting an experiment to test this theory.

to prepare an oil shale deposit for *in-situ* (in-place) retorting. If a sufficient volume of broken shale were produced by such an explosion, retorting techniques could be tested in a second phase of the experiment.

Underground Gas Storage

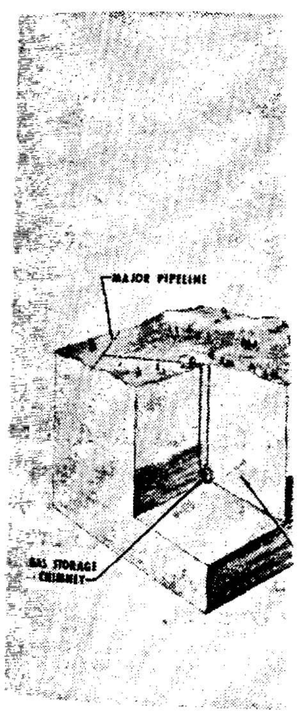
Increasing use of natural gas has brought a demand for more storage capacity than can be met by existing underground storage reservoirs, such as depleted natural gas fields and aquifers near major consuming methods. Present indications are that the demand for gas storage capacity will grow by at least 175 billion cubic feet per year. Creating large underground chimneys by nuclear explosions appears to be one promising method of providing new storage capacity near the consumer-end of gas transmission lines.



Study Shows Feasibility

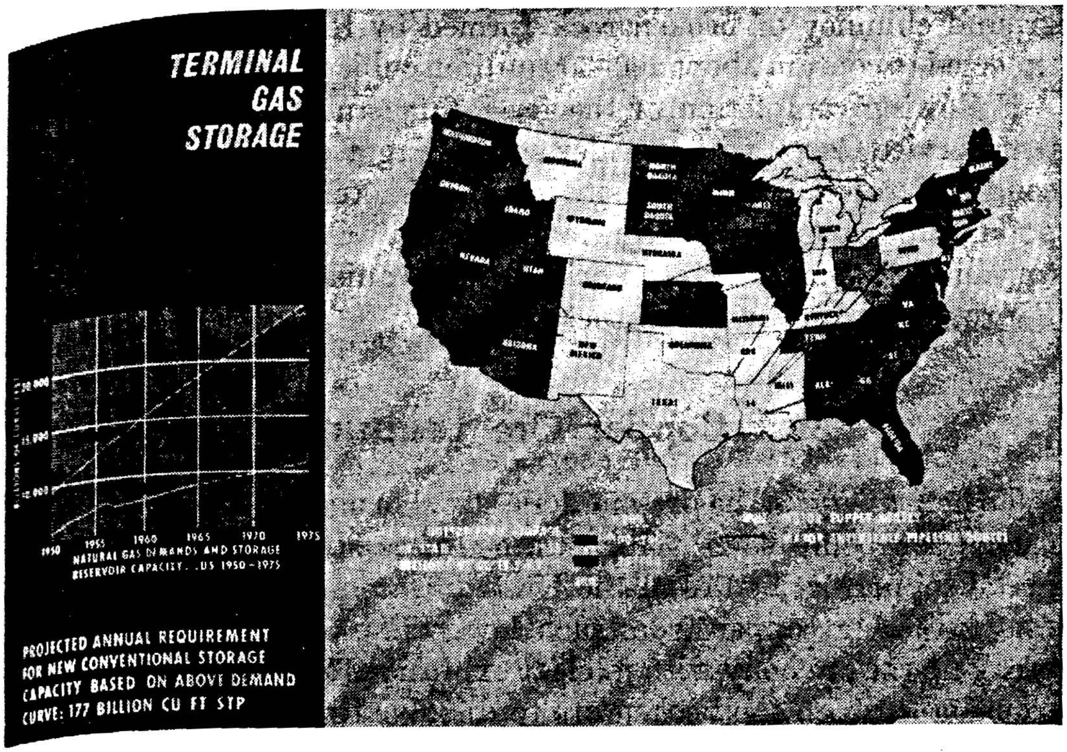
A study group including representatives from the Columbia Gas System Service Corp., Columbus, Ohio, the USBM, the AEC's San Francisco Operations Office, and the Lawrence Radiation Laboratory, Livermore, is completing a feasibility study of the use of nuclear explosions to create underground storage areas for natural gas. To date, the findings of the study indicate that a nuclear-chimney could provide storage for up to 10 million cubic feet of gas per kiloton of explosive yield. Even greater storage capacity may be possible if pressures higher than hydrostatic pressure at the chimney's depth can be used.

It is expected that gas stored in a nuclear-chimney could be produced over a very wide range of flow rates using standard well equipment. Calculations made for flow rates from 10 million to 500 million cubic feet per day from a chimney produced by a 50 kiloton explosion indicate that optimum investment costs would be from \$2 to \$4 per thousand cubic feet of usable gas storage capacity at hydrostatic pressure and even less, if higher pressure can be used. This compares with costs of \$0.50 to \$1 for storage in depleted gas fields; \$1 to \$2 for storage in natural aquifers; and \$6 to \$12 for storage of liquified natural gas.

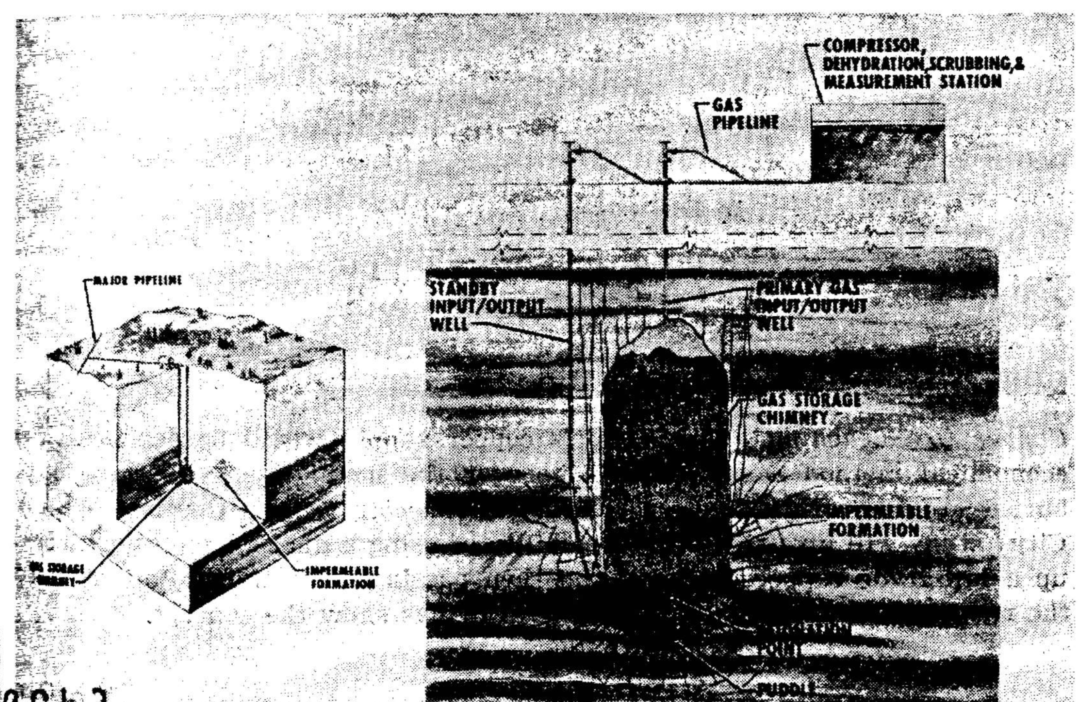


Project Ketch

The joint Government-industry feasibility study of the gas storage application includes a technical concept of an experiment to test the findings of the study. The experiment, named Project Ketch, would use a 20-to-30-kiloton nuclear explosive emplaced at a depth of about 3,300 feet in a drilled hole about 18 inches in diameter. The under-



Terminal Gas Storage. In recent years, the natural gas industry has used underground caverns and depleted natural gas wells to supplement conventional aboveground facilities to store natural gas near consumers in order to meet peak demands. Present, and foreseen increases in use of natural gas indicate that a much greater storage capability will be needed at the end of, or adjacent to, transmission lines. The Columbia Gas System Service Corp., Columbus, Ohio, has suggested to the AEC that a nuclear explosive be used to create a "chimney" in a relatively impermeable rock formation which could be used for storing gas. The drawing *above* shows the relationship of the gas-producing and user States, the major transmission lines, and the projected demand and required storage curves. The drawing *below* portrays the concept for creating terminal gas storage reservoirs by nuclear means.



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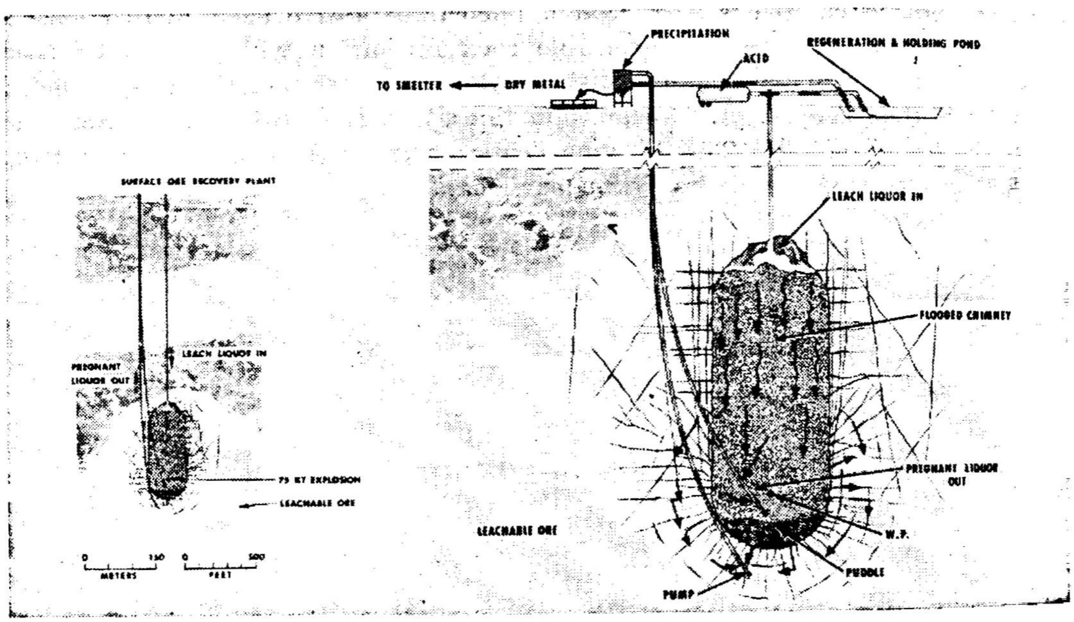
ground chimney of broken rock formed by the detonation would be expected to contain about 200–300 million cubic feet of storage capacity.

Following completion of the feasibility study, Columbia Gas System Service Corp., will consider submitting a proposal to the AEC to conduct Project Ketch at a site locally remote, but regionally close to population centers in its service territory. Columbia's service territory includes parts of New York, Pennsylvania, Ohio, Maryland, West Virginia, Virginia, and Kentucky.

Copper Ore Leaching

To help alleviate the present domestic shortage of copper, economical means are being sought for mining increasingly deeper and lower grade copper ore bodies in the United States. A proposed technique for extracting copper from such low-grade, deeply buried ore, is to break up the ore body with nuclear explosions and to pass a "leaching" solution through the broken ore to dissolve the copper. The copper-bearing solution would then be recovered from the ore body for processing to separate the copper from the solution. The advantage of dissolving the copper ore in place is that it eliminates the necessity of mining and bringing to the surface the huge quantities of low grade



Copper Ore Leaching. The Nation's copper supply would be enhanced if an economical method were found to recover the metal from low-grade deeply buried ore bodies. A joint Government-Kennecott Copper Corp. (Salt Lake City) study will investigate the feasibility of using a nuclear explosion to break up a low-grade copper ore body and then passing a leaching solution through the rubble to recover the copper. The drawings show the concept.

ore that must be treated for extraction of the copper and then disposed of as was the material.

Leaching of low-grade copper ore, broken but left undeveloped during the mining of higher grade ore has been practiced for many years. The key to such "solution" mining is the breaking of the ore, to permit the leaching solution to come in contact with the copper. Until the development of nuclear explosives there has been no method to break the low grade ore deposits other than mining and this has been too costly in relation to the small amount of copper that could be recovered.

Personnel from the Salt Lake City, Utah, office of the Kennecott Copper Corp., the AEC's San Francisco Operations Office, the USBM, and LRL–L, are conducting a detailed feasibility study of this application. After completion of the study, a field experiment in nuclear ore-breaking and leaching, to be called Project Sloop, may be proposed to verify the study's findings.

Project Sloop

Project Sloop is conceived as a 20- to 30-kiloton nuclear detonation at a depth of about 1,200 feet in a low-grade copper deposit. The experiment would be designed to determine whether copper can be produced economically from ore broken by a contained underground nuclear explosion. After the ore-breaking (explosion) phase of the experiment would come a leaching test to evaluate leaching techniques and radioactivity levels. A primary site in the Safford, Ariz., area has been identified for study.

The question of radioactive contamination of copper ore has also been studied, with the general conclusion that it is a manageable problem since:

(*1*) Concentrations of radioactive isotopes in the leach solution would be sufficiently low so that special shielding to protect against radiation exposure would not be needed; and

(*2*) The most troublesome radioactive isotopes would probably be those of metals, such as silver 110, zirconium 95, niobium 95, and ruthenium 106. Fortunately, the relatively non-volatile radionuclides would be locked in the congealed "puddle glass" at the bottom of the cavity and only a small percentage would enter the leach solution. Subsequent metallurgical processing by a newly developed solvent extraction process may remove virtually all radioactive contaminants from the finished copper.

OTHER ENGINEERING ACTIVITIES

In addition to laboratory studies in support of specific proposed underground engineering projects, general research and development activities were continued in 1966 to increase the understanding of the effects of underground nuclear explosions and to improve excavation technology.

CAVITY AND CHIMNEY STUDIES

Studies of past underground detonations as well as current experiments are providing information on cavity and chimney development on a practical as well as theoretical basis.

Handcar Chimney Studies

To learn more of the shape, volume and composition of chimneys produced by underground nuclear explosions in hard rock, a vertical exploratory hole was drilled into the top of the chimney created by the November 1964 Project Handcar[3] experiment—12 kilotons at a depth of 1,320 feet in dolomite at the Nevada Test Site (NTS). The top of the chimney was found to be 223 feet above the shot point, a height about 23 percent less than had been expected on the basis of experience in granite.

Pressurization tests indicate a total void volume in the chimney, including the empty spaces between the rubble particles, of about 1,315,000 cubic feet. This corresponds to a radius of about 68 feet for the initial cavity produced by the shot. An optical survey and stereophotographs show that the void space at the top of the chimney above the rubble is more than half the volume of the original cavity.

Cavity Collapse and Chimney Development

To improve understanding of how chimneys develop above the cavity produced by an underground nuclear explosion, LRL–L, performed a NTS experiment in which information was obtained on the collapse of the alluvium overlying a nuclear explosion at a depth of 1,125 feet. As is typical of underground explosions in alluvium, the collapse of the material above the cavity extended all the way to the surface and produced a "subsidence crater." Collapse data were obtained for points on the surface and beneath the surface down to a depth of 750 feet. Surface collapse was monitored by photographing

[3] See p. 162, "Annual Report to Congress for 1964", and p. 208, "Annual Report to Congress for 1965."

a series of targets resting on the surface above the shot; underground collapse, by special detectors. Particle velocity and acceleration measurements were also made.

As expected from earlier studies, the collapse was massive and rapid once it began; the propagation rate of the collapse front was 100 to 150 feet per second. At a given depth, the collapse was found to start about three seconds earlier in the center of the chimney than at the edges. This lag continued as collapse progressed upward from the cavity to the surface.

Similar chimney development studies are needed for other materials besides alluvium, particularly for materials that are likely to be encountered in some of the proposed underground applications of nuclear explosions.

Prediction of cavity size. A study conducted at LRL–L, has shown that the water content of the host rock affects the size of cavities produced by nuclear explosions. An equation was derived which describes the cavity dimension when the rock density, water content, depth of the explosion, and explosive energy are known.

Re-Entry Technique

During the year, LRL–L, developed a cost-saving technique for re-entering the cavity produced by a nuclear explosive through the original device emplacement hole. Using this technique to re-enter the cavity produced by the Salmon event,[4] a saving was made of approximately 50 percent of the cost of drilling a second hole of the same size and depth. (See discussion on "Project Sterling" in Chapter 5—The Nuclear Defense Effort.) With an emplacement hole and emplacement hardware designed specifically for re-entry purposes, an equivalent or greater saving could be realized on future Plowshare projects, particularly those in which a relatively large diameter hole can be useful for commercial purposes after the explosion.

EXCAVATION TECHNOLOGY

For nuclear excavation technology to advance to the stage where it can be used in large construction projects, the following major technical questions must be answered:

(1) How does crater size depend on geologic properties?
(2) Can data on crater size, seismic effects, acoustic waves, and radioactivity distribution of low yield experiments be extended to yields in the megaton range?

[4] See pp. 163–164, "Annual Report to Congress for 1964."

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(3) How do nuclear charges in a row interact?
(4) Can projects for nuclear excavation of channels through terrain varying in rock type and elevation be designed with confidence?

To answer these questions a number of excavation experiments are required and, to this end, the nuclear cratering experiment Cabriolet was designed by LRL–L. In addition, the U.S. Army Corps of Engineers' Nuclear Cratering Group (NCG) initiated Pre-Gondola,[5] a series of chemical high explosive experiments near Ft. Peck, Mont.

Project Cabriolet

Cabriolet, a low yield nuclear cratering event in hard, dry rock was readied at NTS during 1966 and has been authorized for execution early in 1967. The Cabriolet explosion, which is expected to release an energy equivalent to 2,500 tons (2.5 kilotons) of TNT, will occur 170 feet underground and is expected to form a crater with a depth in the range of 115 to 145 feet, and a diameter of 425 to 460 feet.

Project Cabriolet is an important step in providing essential data on basic cratering effects and the distribution of radioactivity released from a nuclear explosion occurring at what appears to be the best depth underground in a hard, dry rock. Cabriolet will release six times more energy than the largest experiment previously conducted in hard rock at an equivalent depth of burial—Project Danny Boy [6] which released 0.4 kilotons. Although the largest Plowshare cratering experiment to date—Project Sedan [7]—released 100 kilotons of energy, it was done in desert alluvium, a loose sand and gravel material. Thus, Cabriolet will be the largest yield cratering experiment conducted to date in hard rock, the material expected to be the most frequently encountered in future excavation projects.

The information obtained from the experiment will be used in developing further the understanding of how craters are formed. In turn, this understanding is expected to result in increased confidence for predicting the characteristics of craters in other types of rock and from larger explosions. Data from field experiments, such as Cabriolet, combined with the most advanced knowledge of the physical and chemical properties of rock materials and explosion phenomena, provide the input to complex computer calculations which produce a description of the entire cratering process. Thus, each cratering experiment improves the computer calculations, and hence, the overall description of the cratering phenomenon.

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[5] While no specific "Gondola" experiment is currently scheduled, the "Pre-Gondola" term is used to identify this particular series of non-nuclear experiments.

[6] See p. 250, "Annual Report to Congress for 1962."

[7] See pp. 159–161, "Annual Report to Congress for 1964."

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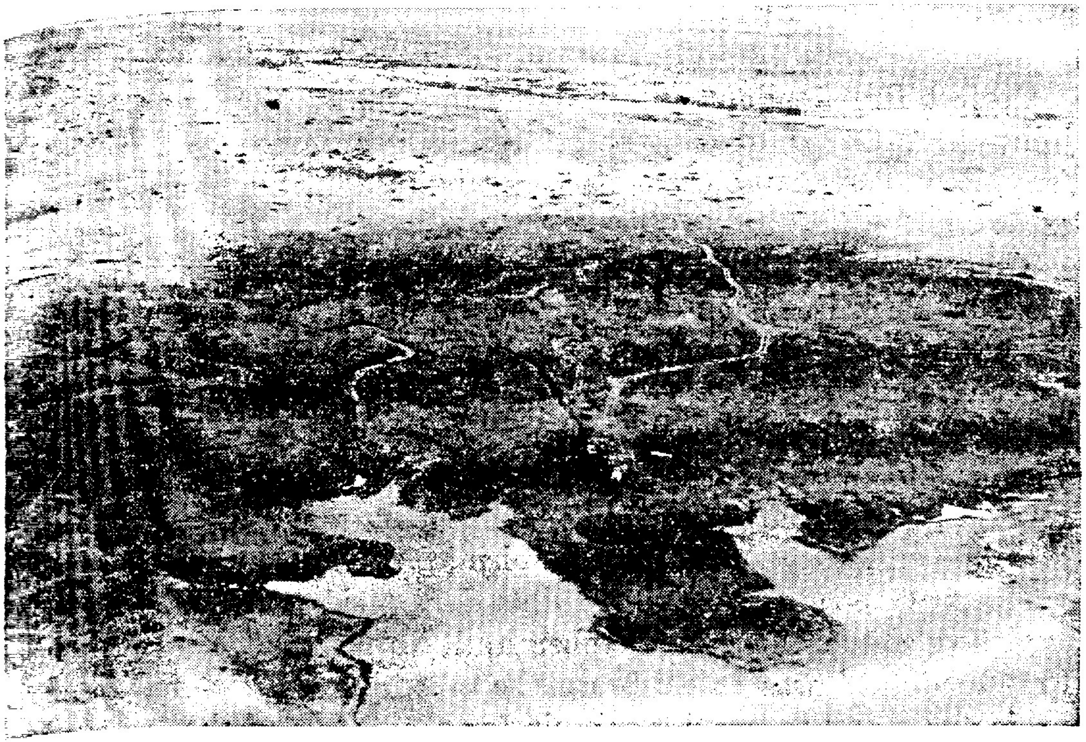
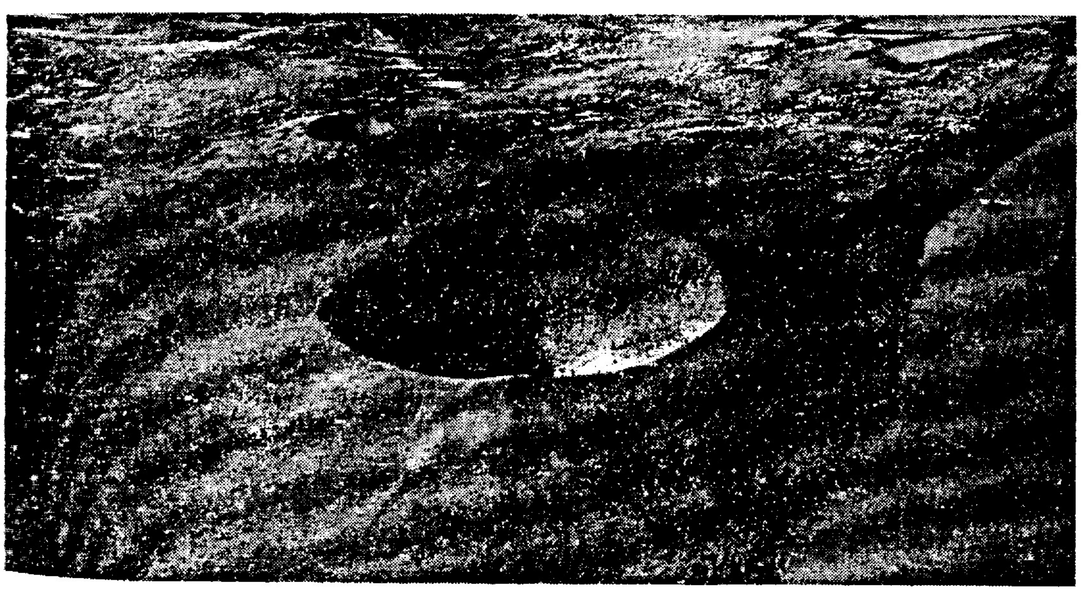


Cratering Experiments. The AEC and the U.S. Army Corps of Engineers are jointly developing experience and information on the cratering and seismic effects of explosives as a prelude to the possible use of nuclear explosives for civil engineering purposes. During 1966, the Corps of Engineers began Project Pre-Gondola, a series of chemical high explosives cratering experiments in weak wet clay shale near Fort Peck, Mont. Shown in the foreground in photo *above* is the crater from a shot detonated below the level of the Fort Peck Reservoir at a total depth of 15.8 feet. Indicated by the arrow is the crater from a shot, detonated at a depth of 23.3 feet in the saturated clay shale. Photo *below* shows the result of a 20-ton nitromethane cratering charge detonated on October 28, at a depth of burst of 42.5 feet in clay shale. It produced an apparent crater 80.6 feet in radius and 32.6 feet deep. The crater in the background is from a 1,000-pound nitromethane charge at a lesser scaled depth of burial.



Pre-Gondola Experiments

Project Pre-Gondola was initiated in 1966 by NCG as part of the joint AEC-Corps of Engineers' research program to develop the feasibility, costs, and other factors involved in nuclear methods of excavation.

This series of high explosive cratering experiments, adjacent to the Fort Peck Reservoir, Valley County, Mont., will extend cratering experience to a weak wet clay shale at the ½, 20, and 100-ton level for single and row charges. The Pre-Gondola series includes single-charge cratering calibration experiments, a row-charge cratering experiment to produce a linear excavation in a varying terrain, and a connecting row-charge cratering experiment.

Following four 1,000-pound seismic calibration detonations in June, NCG conducted Pre-Gondola I, a series of four 20-ton high explosive detonations in October and November. The purpose of Pre-Gondola I was to calibrate the cratering characteristics of the project site and to provide a basis for the design of the 100-ton Pre-Gondola row charge cratering detonations.

Interoceanic Sea-Level Canal

The AEC has undertaken studies and surveys to provide information which the Atlantic-Pacific Interoceanic Canal Study Commission may use to evaluate the safety and cost of using nuclear explosives to excavate a sea-level canal. These activities, which are integrated with other investigations being conducted by the U.S. Army Corps of Engineers and the Panama Canal Co., are part of the over-all engineering feasibility study being conducted for the Canal Study Commission ". . . To provide for an investigation and study to determine a site for the construction of a sea-level canal connecting the Atlantic and Pacific Oceans . . ." in accordance with Public Law 88–609.[8]

On-Site Surveys Authorized

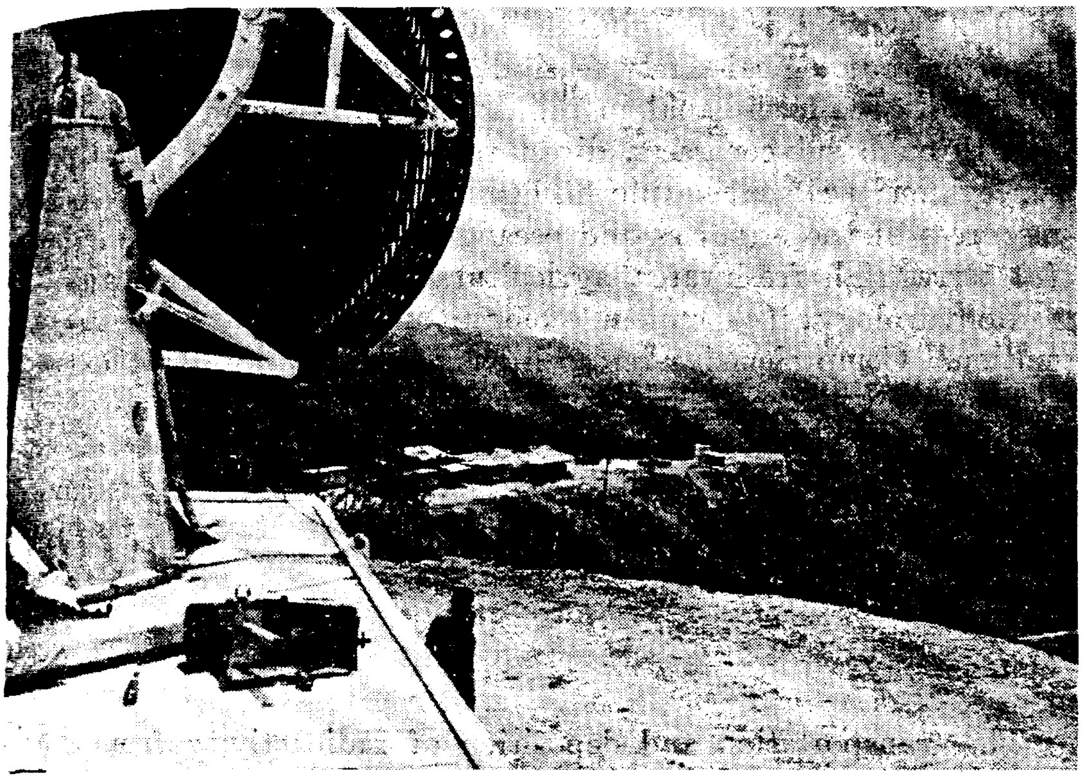
Exchanges of notes between U.S. Ambassadors and the Foreign Ministers of Panama and Colombia were concluded on February 15 and October 25, respectively, authorizing the Government of the United States to engage in on-site surveys in those countries. These agreements enabled the AEC to begin on-site safety feasibility surveys in the area of proposed Route 17 (Sasardi-Morti) in the Darien

[8] See pp. 196–197, "Annual Report to Congress for 1965."

region of eastern Panama and will permit initiation of full-scale field activities both there and at Route 25 (Atrato-Truando) in Colombia beginning in January 1967.

Acoustic Wave Program

Soundings of the upper atmosphere were begun in Panama on March 9, with the firing of the first stratospheric weather rocket. These rockets, which will be fired weekly over a two year period, release metallic chaff at high altitudes. The chaff is then tracked by radar in-



Canal Study. A tracking radar station is shown at a remote meteorological observation outpost established by the Environmental Science Services Administration (ESSA) within the jungle of Darien Province, Panama, to support United States sea level canal feasibility studies. The U.S. Atlantic-Pacific Interoceanic Canal Study Commission is carrying out feasibility studies to determine where and by what method, conventional or nuclear, a sea level canal should be excavated. The AEC is responsible for conducting safety feasibility studies with respect to possible effects of radioactivity, air blast, and ground shock that might be associated with possible nuclear excavation; these studies are part of and support the over-all engineering feasibility studies. The AEC meteorology program being conducted by ESSA is studying wind directions and velocities, and precipitation. The radar unit shown here tracks wind patterns to as high as 60,000 feet. A second nearby radar unit scans the horizon as far away as 100 miles looking for rainfall. Data developed by these activities will be evaluated to establish weather patterns which would be necessary to safely conduct nuclear excavation if it is decided to construct a sea level canal using nuclear explosives.

dicating the speed and direction of winds at altitudes of 100,000 to 200,000 feet. Other rockets are also being sent aloft to obtain temperature ranges at high altitudes and to supplement wind direction and velocity data obtained from the chaff rockets. This information will be evaluated to provide a capability to predict long-range transmission of acoustic waves from nuclear cratering explosions, and their possible effects on man-made and natural structures.

Bioenvironmental Program

The Battelle Memorial Institute (BMI) of Columbus, Ohio, under an AEC contract, is managing the bioenvironmental studies to determine the radiological-safety feasibility of using nuclear explosives to excavate a sea-level canal in the American Isthmian region. BMI will through sub-contracts, direct studies and the necessary on-site surveys on: (*a*) marine physiochemistry and biology; (*b*) fisheries resources of the estuaries and oceans on both sides of the isthmus; (*c*) terrestrial, freshwater, agricultural, and marine ecologies; (*d*) radiohydrology; (*e*) human ecology; and (*f*) radiation dose estimation. Comprehensive research has been undertaken to determine the essential information which could be obtained from site surveys and detailed plans made for collecting data in the probable route areas. Scientists will go into the field to collect specimens and develop information during the January through March dry season in 1967.

Meteorology

The transportation and deposition of radioactivity from nuclear cratering explosions depends to a large extent on meteorological conditions at the time of the detonations and for an indefinite period afterward. The Environmental Science Services Administration (ESSA). under AEC contract has designed, and is conducting, a two-year meteorological program to develop sufficient information for a safety feasibility study of this question.

Two weather stations have been constructed and were placed in operation on Route 17 in the Darien region of Panama. One is located at Pidiaque, a few miles in from the Pacific Ocean and the other on Soskatupu Island in the Caribbean Sea. These stations, operating 24 hours a day, are collecting data on wind patterns and rainfall. Wind measurements are made by tracking balloons with radar four times daily at altitudes up to 60,000 feet. Low-level measurements are also made on 150-foot towers to determine local wind flow. The Pidiaque station, near the Pacific, makes continuous observations of precipitation within a radius of 60 miles. Information is obtained in-

dicating density and location of the rain and the altitudes to which the rain extends.

Similar stations will be constructed and manned in Colombia near Route 25 in 1967.

Excavation Research and Development

Special Explosives and Emplacement Techniques

One major goal of the excavation development program is to reduce the amount of radioactivity released to the atmosphere to an absolute minimum. Efforts have continued on the development of explosives with a minimum of fission and induced radioactivities and on special emplacement techniques. Three tests related to this program were conducted by LRL–L with very encouraging results.

Cratering Calculations

LRL–L, has developed a computer-based technique for calculating the mound and cavity growth during nuclear and high explosive cratering explosions. The calculations feature a standard numerical approach to high intensity stress-wave propagation, coupled with a unique model of material behavior. The properties of the earth materials are determined from geophysical logging at the site of the event and from laboratory tests of rock samples. With this information, the computer code calculates the extent of the ejected material, the resulting crater radius, and the mass deposition. The calculations since made with this technique for the 1962 Danny Boy experiment are in good agreement with the actual radius and ejecta deposition. A next step in the calculation effort is to determine the bulk volume of material that falls back into the crater to obtain crater depth. This then will lead to studies of the stability of the slope of the resulting crater.

Acoustic Wave

Acoustic waves emitted from a nuclear explosion at excavation depth produce an effect, similar to a "sonic boom," close to the explosion and sometimes, at more distant locations where the acoustic waves may be focused by atmospheric conditions. This effect of nuclear cratering explosions is being examined at LRL–L where scientists are calculating both the close-in air shock and the long-range acoustic signal refracted in a layered atmosphere. LRL–L is using these calculations to develop computer codes which will be applied in making acoustic

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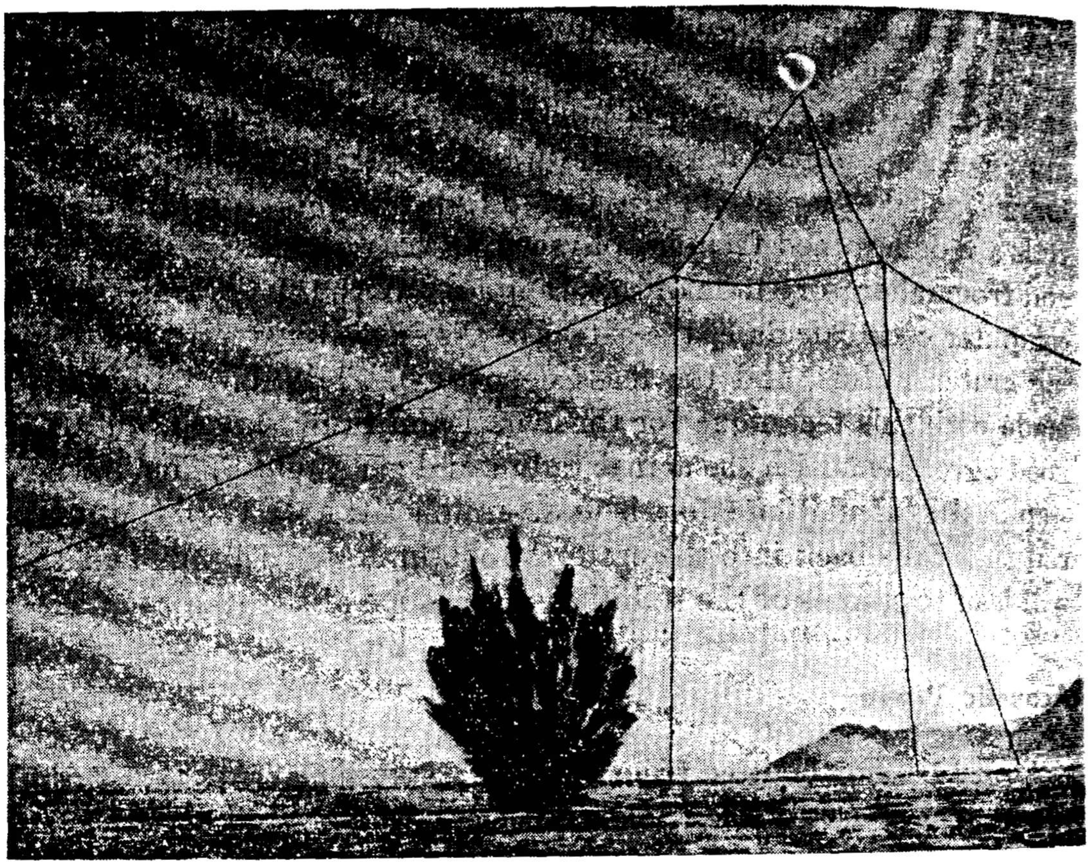
ave predictions for various sizes of explosions under various atmospheric conditions.

Also during the year, the Sandia Laboratory, operated for the AEC by the Sandia Corp., performed field studies of acoustic effects near the explosion. To determine the relationship of the strength of the acoustic wave to the depth of the detonation, single charges of 1,000 pounds of high explosives were detonated at Sandia's Coyote Canyon test area near Albuquerque, N. Mex. Gauges were suspended under balloons to measure the energy released from the explosion and to determine its geometry. In addition, Sandia examined variations in air effects from simultaneous and sequentially fired row charges. This series of experiments was conducted at the Tonopah Test Range in Nevada using 64-pound charges, spaced six to eight feet apart and buried six feet deep.

Sandia's close-in measurements, coupled with distant recordings, will aid in the further understanding of acoustic wave transmission and thus will enhance the ability of project designers to avoid damage from this source.



Air Blast Experiment. As a part of developing the use of nuclear explosives for earth moving, the Sandia Laboratory has been conducting a series of chemical (high explosive) experiments to determine various effects. The retouched photo shows gauges (*small dots*) attached to balloon-supported guy lines to measure the acoustic effect from a 1,000-pound high explosive cratering experiment near Albuquerque, N. Mex. Such experiments provide information that can be scaled-up to predict the effects from nuclear detonations.

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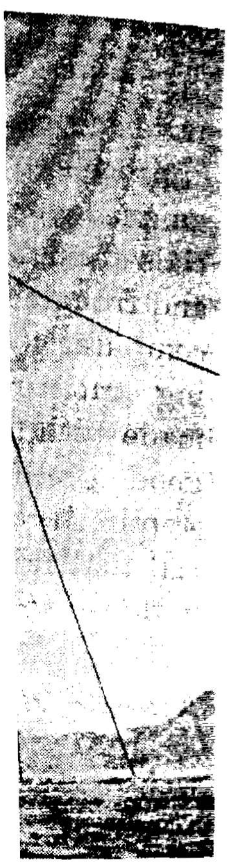

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High-Explosive Cratering Experiments

The Sandia Laboratory's small-scale, high-explosive cratering investigations using single and multiple charges, ranging from 8 to 256 pounds each, continued during the year.

These experiments, conducted since 1959 as a part of the Plowshare Program, are generating the preliminary information for the design of larger-yield high explosive and nuclear excavation experiments which will follow. For example, in one experiment, twenty-five 64-pound charges in a spread pattern of three offset rows were detonated one at a time, followed by 11 charges placed beneath the crater of the first 25, also detonated one at a time. The resulting crater compared favorably with one resulting from simultaneous detonation of eight 256-pound charges. The use of 15 percent more total charge weight (2,304 pounds) reduced the amount of high explosives fired at one time from 2,048 pounds to only 64 pounds to achieve the same results. This is important from both acoustic and seismic wave safety considerations, and it also suggests that deep excavations through high terrain, might be achieved as well by a series of smaller detonations fired one at a time as by larger simultaneous row-charge detonations.

During 1966 studies of the effects of one misfire in a row-charge explosion, emphasized the distribution of ejected material, and the interaction of intersecting single-charge and row-charge excavations.

SCIENTIFIC STUDIES

Heavy Element Research

Plowshare experiments in the heavy element program were aimed at learning more about the exact capture path for producing very heavy isotopes, the extent of fission losses in heavier targets, and improvements in the nuclear explosive to increase the neutron flux. It has been concluded from these investigations that neutron capture in protactinium is the chief source of very heavy isotopes when uranium 238 is the initial target. On experiments in which plutonium 242 and americium 243 were used as target materials, excessive fission losses in the neutron capture sequence prevented significant amounts of very heavy nuclides from being formed. In an experiment performed by Los Alamos Scientific Laboratory as part of the Cyclamen event (see "Production of Heavy Elements" item, Chapter 5—The Nuclear Defense Effort), an improvement in the design of the nuclear explosive increased the attainable flux levels.

There is now some evidence that increased flux levels may not produce continually increasing heavy nuclei as easily as was once expected, particularly at atomic mass 259 and beyond. Neutron exposure in the uranium 238 target of the Cyclamen experiment was sufficient to have made detectable amounts of fermium 259 and/or mendelevium 259. However, neither was detected within a wide range of half-life limits. Possible explanations are being studied, and new investigations into the stability of heavy nuclides are being started. Nuclear explosive design changes are contemplated which should markedly increase the neutron exposure and extend the expected heavy element yield well past atomic mass 259.